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Phase I: Systems Concepts

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Douglas Aircraft Company

Lockheed Aircraft Company

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Final Report, Phase I

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16. Abstract

This report covers Phase I of a study conducted for the FAA to develop flight status monitor concepts. Previous studies of crew alerting systems suggested the concept of a flight status monitor which could monitor a flight, alert the crew to abnormal operations as well as aircraft system failures, and guide the crew through the appropriate response-action procedures. Candidate concepts developed in Phase I will be refined and evaluated in Phase II.

The major Phase I activities reported include:

1. Reviewing the results of Phase IV of the Aircraft Alerting System Standardization Study to identify the requirements for expanding the alerting system into an FSM.
2. Developing preliminary FSM candidate concepts and identifying design issues relating to concept implementation.
3. Performing a literature review to obtain data for answering design questions.
4. Developing realistic demonstration scenarios, based upon previous accidents/incidents, to provide a mechanism for evaluating the candidate concepts.
5. Implementing the FSM concepts and demonstration scenarios in a flight deck simulator for concept demonstration/evaluation.
6. Conducting demonstrations and developing a questionnaire to solicit pilot comments/opinions for refining the candidate concepts and to provide data for resolving FSM implementation issues. *Originator-supplied keywords include:*

Alert, Caution and Warning, Warning Systems, Crew Alerting, Flight Status Monitor, Flight Monitor, Alerting Systems, Human Factors, Voice Control, Touch Panel.

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PREFACE

This study is sponsored by the Federal Aviation Administration and is directed toward the improvement of flight crew performance through the development of standardized aircraft alerting systems for crew alerting and flight status monitoring. Previous studies suggested that a Flight Status Monitor (FSM) could monitor flight status for abnormal operations as well as aircraft system failures and could guide the crew through the appropriate procedures for the situation. The objective of this study is to develop and evaluate FSM concepts. Phase I, conducted between June 1983 and July 1984, consisted of developing candidate FSM concepts, while Phase II will consist of refining and evaluating those concepts. The study is being conducted as a joint effort by the Boeing, Douglas, and Lockheed Aircraft Companies. The primary purpose of this report is to summarize the results of Phase I activities.

The authors wish to express their appreciation for the assistance received from their respective engineering and safety organizations. The assistance and guidance of Wayne D. Smith, the Program Manager and Boeing Flight Systems Research and PD Manager, was of great value. The efforts of the rest of the Flight Systems in fabricating the simulation system was instrumental in the success of the project. The contract sponsor is the Federal Aviation Administration, and technical guidance was provided by John F. Hendrickson, APM-430, the Contract Monitor.

1.0 INTRODUCTION

1.1 PROGRAM HISTORY

The study of aircraft alerting systems and flight status monitor concepts was initiated in 1973 when the Federal Aviation Administration (FAA) contracted with Boeing to study independent altitude monitors. Follow-up studies conducted during 1974 through 1977 investigated operational philosophies for implementing effective and reliable alerting systems. Study results indicated that there had been a significant increase in the number of alerting signals used on newer commercial transports and very little standardization had been used by the airframe manufacturers in implementing alerting system elements. Table 1.1-1 summarizes the major activities accomplished during these studies.

The identification of these problems led to the Aircraft Alerting Systems Standardization Study contract. The contract was performed as a team effort by the Boeing, Lockheed and McDonnell Douglas aircraft companies. The study was to have been conducted in three phases and culminate with the development of design guidelines for improving and standardizing advanced aircraft alerting systems. During the course of the study contract, interest was developed within the FAA in expanding the requirements of the alerting system to monitor flight status and facilitate crew responses to abnormal and emergency situations. A contract modification was made to add a fourth phase to review accident histories and the cockpit environment to determine concept feasibility of a Flight Status Monitor (FSM).

Table 1.1-2 lists the major activities conducted under the Aircraft Alerting Systems Standardization Study.

Table 1.1-1 Early Alerting System Studies — Contract DOT-FA73WA-3233

| Title (Report No.) | Development of an independent altitude monitor concept (FAA-RD-73-168) | Independent altitude monitor alerting methods and modes study (FAA-RD-75-86) | Collation and analysis of aircraft alerting systems data (FAA RD-76-222) |
|-----------------------|--|--|---|
| Objectives | <ul style="list-style-type: none"> ● Identify nature of typical inadvertent terrain impact accident scenarios ● Identify techniques whereby inadvertent terrain impact accidents might be reduced ● Identify functional elements of an independent altitude monitor concept ● Identify methods of implementing independent monitor systems | <ul style="list-style-type: none"> ● Develop operational alert philosophy and concepts ● Demonstrate and refine selected independent altitude monitor alerting methods ● Develop independent altitude monitor implementation plan | <ul style="list-style-type: none"> ● Tabulate current alerting methods and requirements for all cockpit alerting functions ● Develop method for prioritizing alerting functions ● Prioritize alerting functions ● Correlate requirements with prioritized functions and note conflicts ● Broaden stimuli-response data base ● Define tests for acquiring stimuli-response data not available in literature but required for designing alerting systems ● Provide recommendations for standardization of alerting functions and methods |
| Period | February 1973 to September 1973 | June 1974 to July 1975 | January 1976 to May 1977 |

Table 1.1-2 Aircraft Alerting Systems Standardization Study — Contract DOT-FA79WA 4268

| Title (Report No.) | Phase I Define prototype alerting system concepts (FAA-RD-80-68) | Phase II Plan tests for prototype alerting system concept evaluations | Phase III Evaluate prototype alerting system concepts (FAA-RD-81-38 I & II) | Phase IV Accident implication for system design (DOT/FAA/RD-82-26) |
|-----------------------|--|--|--|---|
| Objectives | <ul style="list-style-type: none"> ● Acquire missing stimuli-response data via appropriate simulator tests ● Define alerting system concepts ● Assess physical characteristics of each concept ● Assess implementation feasibility of each concept ● Select alerting system concepts for comparative evaluation | <ul style="list-style-type: none"> ● Select simulation facility ● Develop test plan ● Coordinate test plan with FAA | <ul style="list-style-type: none"> ● Develop brassboard hardware for selected alerting system concepts ● Perform comparative simulator evaluation of selected concepts ● Finalize design guidelines for standardized alerting system ● Assess certification impact | <ul style="list-style-type: none"> ● Analyze aircraft accident and incident data ● Examine the cockpit environment ● Develop expanded alerting system design concepts ● Identify functional components for a FPSM |
| Period | January 1979 to November 1979 | November 1979 to February 1980 | February 1980 to November 1980 | July 1981 to June 1982 |

The Phase IV study showed the feasibility of the concept of expanding the functions of the alerting system to perform as a flight status monitor. A function of the FSM is to monitor and alert the crew to abnormal flight operations as well as abnormal system operation. Functional requirements for the FSM were developed on the assumption that, by providing the crew with guidance and feedback in their response to abnormal situations, their performance could be improved.

Phase IV resulted in the identification of the component functions that might be used to expand an alerting system into a flight status monitor. Specifically, the following additional capabilities are necessary for an alerting system to function as an FSM:

- o Expanded Sensing - To provide additional sources of status data (e.g., low acceleration, wind shear, tire/wheel failure, navigation).
- o More Complex Information Processing - To provide additional computational and data handling capabilities to consider such features as flight phase adaptation, predictive and multiple alerts, and integrated checklists.
- o System Interfacing - To carry out data exchange between the FSM and other data handling systems such as flight management, performance management, flight control, sensor subsystems, navigation, communications, and maintenance data recordings.
- o Displaying - To provide the crew with detailed guidance information to facilitate the response to alerts and feedback after the response has taken place.
- o Controlling - To provide crews with the capability to interact with the FSM.

1.2 PRESENT STUDY

The objective of the present study is to develop and evaluate alternate FSM concepts for providing crew guidance and feedback to facilitate crew and system effectiveness. This effort will be accomplished in two phases.

The major Phase I activities have included:

1. Reviewing the results of Phase IV of the Aircraft Alerting System Standardization Study and other relevant data sources to identify the requirements for expanding the alerting system into an FSM.
2. Developing preliminary FSM candidate concepts and identifying design issues relating to concept implementation.
3. Performing a literature review to obtain data for answering the design questions generated by the team.
4. Developing realistic demonstration scenarios, based upon previous accidents/incidents, to provide a mechanism for evaluating the candidate concepts.
5. Implementing the FSM concepts and demonstration scenarios in a flight deck simulator for concept demonstration/evaluation.
6. Conducting demonstrations and developing a questionnaire to solicit pilot comments/opinions for refining the candidate concepts and to provide data for resolving FSM implementation issues.

In Phase II, a simulator suite will be developed to evaluate the utility of the refined concept(s). Line qualified pilots will "fly" a simulator in predefined scenarios and be exposed to a number of different abnormal and emergency conditions.

1.3 REPORT ORGANIZATION

Section 2 of this report describes the procedure used to develop and refine the preliminary FSM concepts. Scenarios developed to demonstrate FSM concepts are presented in Section 3. Section 4 describes the objectives, procedures, facilities, and results of the FSM demonstrations. Section 5 summarizes the Phase I accomplishments and provides recommendations for future FSM activities. Appendix A contains details of the literature review studies, while Appendix B shows the questionnaire which will be used to collect pilot opinion data.

2.0 CONCEPT DEVELOPMENT

2.1 PHASE IV CONCEPT OF THE FSM

The Phase IV study suggested that the alerting system should monitor flight status for abnormal operations as well as mechanical failures and that the system should guide the crew through the appropriate procedures for the situation. This finding supported an early program assumption that the basic functions of a crew alerting system should include:

Alert (Attention-Getting).
Inform (Identify the Problem).
Guide Crew Action.
Provide Feedback.

The results also indicated that it would be feasible to expand the alerting system, as described in the guidelines (Berson, Po-Chedley, Boucek, Hanson, Leffler and Wasson, 1981), to provide an FSM capability. Phase IV objectives for the FSM included requirements for:

- o Flight Phase Adaptation - The Phase IV accident survey showed that 60 percent of the accidents occurred during takeoff, final approach, and landing. These critical flight phases are characterized by increased crew activity and coordination. The flight crew should be protected from distractions from the piloting tasks during these flight phases. Flight phase must be taken into account when determining alerting requirements. Alert prioritization and inhibition schemes should be considered in FSM design.
- o Multiple Alert Capability - The survey showed that in 73 percent of the accidents/incidents reviewed there were multiple causal factors. It is unknown how many of the multiple factors occurred simultaneously; the accident histories report very few occasions where alerting devices were activated. However, it is assumed that there can be failures precipitated by multiple and unrelated failures over a short period of time. When these alerts are presented to the crew in the form of multiple and simultaneous alarms, crew workload can significantly increase. The system should be able to quickly and reliably determine the relative criticality of the alerts and display them to the crew for their response.
- o Guidance and Feedback - The FSM should be capable of facilitating the completion of the appropriate procedural steps in response to alerts. The accident survey showed that:

- o 19 percent of all accidents were caused primarily by crew error involving failure to follow approved procedures
- o 11 percent of all accidents caused primarily by crew error involved pilots taking the wrong action or taking no action when one was required
- o 6 percent involved misunderstood instructions

2.2 REFINEMENT OF PHASE IV CONCEPTS

In developing the alternative FSM design requirements, current commercial transport aircraft procedures such as described in the TWA Flight Handbook for the 767 were reviewed. In general, current alert resolution procedures consist of cancelling the master warning/ caution indicator, performing the memory items (i.e., those actions requiring immediate attention for a warning alert), searching for and reading the abnormal procedure on the checklist cards, performing the procedure, and, when time is available, checking the flight manual for secondary procedures and information relative to the emergency. Each procedure in the checklist and flight manual is prefaced by the failure. The first part of the procedure lists the actions necessary to contain or correct the abnormal situation. The second part reviews flight plan information, and, if required, special tasks for configuring the aircraft for landing.

Based on the review and Phase IV results, the study team concluded that the following information could aid the crew in responding to alerts:

- o Procedures - Step-by-step listings of the actions required to resolve the alerting situation. These are currently provided by a combination of crew memory items and procedures contained on checklist cards and amplification in flight manuals.
- o System Configuration - Representation of the operation and function of aircraft subsystems (e.g., hydraulic, electric). Presently, this information is currently either remembered by the pilot or described in the operations manual.
- o Failed-System Status - Representation of the impact of faulted subsystems with indications of the failed components. This information is presently contained on the systems panels.

- o Aircraft Status - Representation of the impact of faulted systems on the operational limits and aircraft flying qualities. This information is either described in the operations manual, flight manual, or remembered by the crew.
- o Information - Information pertaining to the alerting situation which is relevant to the remainder of the flight (e.g., plan for a 20° flap landing). This information is currently contained in the checklist cards and the flight manual.

The study team proposed that the above information could be presented on two multi-function color displays:

1. A procedures display, providing step-by-step action items for resolving alerting situations.
2. A status display providing aircraft status (including the impact of faults on aircraft operating conditions, limits, and flying qualities), system status, and pertinent information.

It was assumed that these two displays should have both graphic and alphanumeric capabilities, and that they could accomplish all of the FSM functional design requirements identified previously.

2.2.1 FSM Design Issues

During concept development, various design issues were identified which require additional research and evaluation. These issues include procedures and status display content, format, method of information coding, and symbology design. Other issues involve crew interactions with the FSM displays, mechanisms for performing procedural action items, and mechanisms for implementing alert prioritization, inhibition, and flight phase adaptation schemes.

2.2.1.1 Procedures Display Design Issues

Conceptual formats for the procedures display include word checklists, word descriptions, and task flow diagrams. The symbol or character design issues, i.e., resolution, brightness contrast, character size, and font etc., are covered by basic human engineering practices in the design of

electronic displays. The procedures display developed, assumes a capability to: (1) provide step-by-step procedural information for resolving alerting situations, (2) integrate procedures for handling multiple failures, and (3) provide feedback as to the adequacy of the crew's response. The primary design issues in implementing these capabilities include:

1. Information Content - Should memory items, abnormal procedures, advisory information, or normal checklists be presented?
2. Presentation Format - Should alphanumeric listings, task flow diagrams, voice messages, or combinations of the above be presented?
3. Coding Dimensions - What dimensions should be used for coding information: color, size, shape, brightness, etc.?
4. Number of Action Items to Display - How many action items should appear on one page: one (present action), three (past, present and next actions), or a full page of items?
5. Syntax - What type of syntax should be used to present procedural information?
6. Duplication of Procedures - Should the procedures look the same as the procedures in the flight operations manual?
7. Abbreviations - When and how should abbreviations be used?
8. Branching Statements - How should branching be handled for both interactive and non-interactive procedures?
9. Multiple Alerts - How should multiple alerts be handled, if alerts are of the same or different alert levels?
10. Noncompleted Actions - Should the crew be allowed to skip steps and how should the noncompleted steps be indicated?
11. Procedures Completion - What should happen to the procedures display after the alert resolution procedures have been completed?

2.2.1.2 Status Display Design Issues

As discussed previously, status information may aid the crew in correcting a fault and assist them in identifying changes in the aircraft's operational limits. The following types of status information could be presented:

1. A display of the failed system to identify the fault.
2. A display of the system wherein the procedural steps are being performed to obtain feedback on crew and system actions.
3. Aircraft status to indicate changes in operational limits and flight status.

Various format concepts for the status displays have been suggested, including alphanumeric lists, pictorial system schematics, and voice messages. As in the design of the procedures display, basic human engineering design principles need to be applied, with special attention to the simplification of pictorial information and the use of the coding dimensions.

Status display design issues include:

1. Information Content - Is aircraft status information required for the crew to resolve alerting situations? What type of information should be provided: failed systems, operational limits, or other information? How much information should be presented: the faulted portion of the system or the entire system? Should quantitative information be presented and if so, by numerics, graphics, or both?
2. Type of Format - Should status information be presented pictorially such as by schematics, alphanumeric lists, voice messages, or any combination of the three?
3. Information Coding - What display dimensions should be used for information coding, such as color, shape, brightness, and shading?
4. When to Present Status Display - Should status information be presented during alert resolution, after alert resolution, or at any time desired by the crew?

5. System Panel Similarity - If system overhead panels are used and subsystem status information is presented on the status display, how closely should the status information resemble the information on the overhead panel?
6. Level of Detail - How much detail should be provided? Should data be presented from a detailed level to a general level, or vice versa?

2.2.1.3 Crew Interaction Issues

The main crew interaction issue involves the amount of automation provided by the FSM. The following levels of automation were identified:

1. Manual - Crew is required to manipulate the FSM displays and to perform the corrective actions manually.
2. System Aided - Some FSM system operation is automated. Crew interaction with the aircraft systems is through the FSM system. The crew interacts with the system by the use of multifunction interactive devices, such as multifunction keyboards, touch panels or voice actuation.
3. Automatic - Crew interaction is minimal. Crew is only required to initiate system reconfiguration, and the FSM performs the control actions.

There are two categories of crew interaction associated with the FSM: (1) control of the FSM displays, and (2) control of the aircraft systems associated with the FSM procedures. The following design issues were developed with regard to these types of interactions:

1. Method of Display Control - Should the FSM displays be called up manually or automatically? Should call up depend upon the alert level or the type of information, i.e., procedures or status?
2. Type of FSM Display Control - Should line select keys, a multifunction keyboard, a touch panel, or a dedicated keyboard be used to control the FSM displays? Should voice control be a primary mode of control or only be used as a backup?
3. Method of Aircraft System Control - Should pilot-aircraft system interaction be performed manually via dedicated system panels (i.e., the overhead panel), system-aided where the interface is

through the FSM system, or automatic? If automatic, should the crew be capable of stopping a procedure or reconfiguring the system after the automatic reconfiguration occurs?

4. Type of Aircraft System Control - What device should be used for FSM crew interaction; a multifunction keyboard, a touch panel or voice actuation? Should a multifunction keyboard be arranged by the sequence of events or by the structure of the subsystem? With a touch panel, should control be via a softkey (software controlled function) adjacent to the procedure, a softkey next to the component on the system schematic, or by a component symbol itself?

2.2.2 Literature Review Summary

As previously mentioned, the preliminary FSM concepts proposed two multifunction displays, one to show procedural action items and one to provide status reports. Crew interaction devices include line address keys, touch panels, dedicated keyboards, and voice input systems emerging as potential FSM candidates. In addition, numerous questions were identified relating to the design and implementation of these displays and interactive devices. Therefore, a review of the published literature was conducted to obtain data for resolving these design questions. Comparisons of different display and control formats were sought. Although many descriptions of "checklist"- and "schematic diagram"- type displays were found, no comparison studies or "hard" empirical data could be located. The studies described then do not present statistical results to support or refute the use of any specific mechanism; instead, they present display and control formats as designed by professionals according to unique sets of requirements. Among systems currently reported in the literature, no standardization exists.

With the exception of one source, all articles described checklist and schematic presentation formats as part of an integrated system. An integrated system is one where displays and controls are designed simultaneously and are incorporated into a complete, interactive system. Thus, one

would not discuss a portion of an integrated system as an independent unit, but would instead refer to all units as a total system.

Therefore, the literature found on integrated systems will be described first, followed by a review of articles which discuss schematic diagrams, then information pertaining to touch panels and voice input/output systems will be given. Appendix A contains details of system designs, when such details were provided by the authors.

2.2.2.1 Integrated Systems

In a discussion of flight displays for the next generation aircraft, Dunn (1976) suggested using checklists with logic routines, where sensed failures could lead to the automatic display of appropriate checklist procedures. He also suggested that automated checklists could improve crew efficiency and performance effectiveness. However, Dunn emphasized that research should be conducted to determine the best method of implementation.

Wasson and Archer (1981) examined how advances in technology (such as touch panels and voice input) could affect Lockheed's 1990's flight station. The authors recommended an integrated display and control system for future aircraft, where one display is capable of showing schematic system diagrams and presenting checklists with operator interaction via a touch panel. They mentioned voice input as another crew interface modality. Applying voice input would free the eyes and hands for other tasks, but voice input should not be used for all control tasks. Safeguards should be employed to prevent accidental activation through normal cockpit conversation. Potential applications of voice systems include accessing information (i.e., checklists) and entering data.

Gartner and Holzhausen (1979) described a Touch Input Control Device to be used as part of an integrated cockpit display and control system. The authors suggested that displays and controls for several airborne systems could be combined into one space and located in the pilot's primary field

of view. They also recommended a multifunction display for future aircraft, where several types of information could be presented (such as checklists and system schematics). Touch panels would be used to control the display of these items. The authors presented an example of an Integrated Flight Management System containing several components, including computer controlled checklist procedures. To access the checklist and perform the necessary procedure, the operator chooses desired functions via a series of functional task selection keypads presented on the screen in sequential (hierarchical) order. Details of this process are presented in Appendix A.

Streeter, Weber, and Opittek (1973) conducted the "Master Monitor Display Study". An integrated display system was devised which contained warning and caution information, mode advisory data, functional failure information, and auxiliary data all presented on the same display surface. In addition to the general categories mentioned above, checklist procedures from the F-14A aircraft were presented. One display format was selected which could accommodate both quantitative and qualitative data. Six data levels were presented ranging from system status data to fault-correction procedures (checklists). The progression through data levels (as described in Appendix A) was accomplished either manually or automatically. Schematic diagrams were presented at the SUBSYSTEM level, indicating both normal and faulted conditions. Checklist procedures were presented at the PROCEDURAL level (the most detailed of the six levels). Figure 2.2.2.1-1 shows a checklist procedure.

The authors did not see any functional utility of schematic presentations, so this mode was not discussed in much detail. It was stated that such a presentation may help highly skilled pilots explore alternative methods to correct a malfunction. Schematic diagrams were demonstrated only to show the display system's capability.

OUTBOARD SPOILERS

FLUID LEVEL 0

PRESSURE 0

PROCEDURE

1. LAND ASAP

2. OUTBOARD SPOILER OFF

USE GND CK PANEL SW

INOP EQUIP:

OUTBOARD SPOILERS

FLAP/SLAT BACK-UP

DLC/ACL

OTHER SYSTEMS - NORMAL

Figure 2.2.2.1-1 Sample Checklist Procedure (Streeter, Weber, and Opittek, 1973)

Perhaps the most comprehensive design of checklist and schematic presentation formats was undertaken by Sexton (1983), in an effort to describe a conceptual design for a 1990's transport aircraft. Several topics were discussed by Sexton, including symbology and symbol logic of schematic diagrams. The major coding requirement for symbology was the need for consistency, especially with related formats such as functional systems formats. Figure 2.2.2.1-2 demonstrates some examples of the symbology used on functional systems formats. Symbology, symbol logic and color coding interact in several cases.

Several requirements were also listed for voice command and response. Basically, Sexton noted that voice input could be used to call up information such as checklist procedures; voice output (or synthesis) could be used to automatically convey time-critical messages, or to read warning, caution, and advisory messages on demand. Checklist item completion could require use of voice input and checklist readout could require voice output.

Touch panel technology may be used for checklist item completion and switch function control on system schematics. Touch switches were also used for PAGE, STORE and RECALL functions for caution and advisory level alerts. Checklist operation for both normal and abnormal procedures is presented in Appendix A.

The only operational aircraft that provides checklists on electronic displays is the A310, which has the Electronic Centralized Aircraft Monitor (ECAM). The ECAM provides the crew with checklist and status information for both normal and abnormal flight situations. The information is presented on two centrally located CRT displays, by means of alphanumeric messages and system synoptics (generalized schematics of aircraft systems). A control panel is provided for clearing the display, calling up status information, recalling a procedure, and selecting system synoptics. A conventional annunciator panel is used. Aircraft system controls are located on the overhead panel. Thus, the ECAM is a display system which uses CRTs for the presentation of procedural messages and status

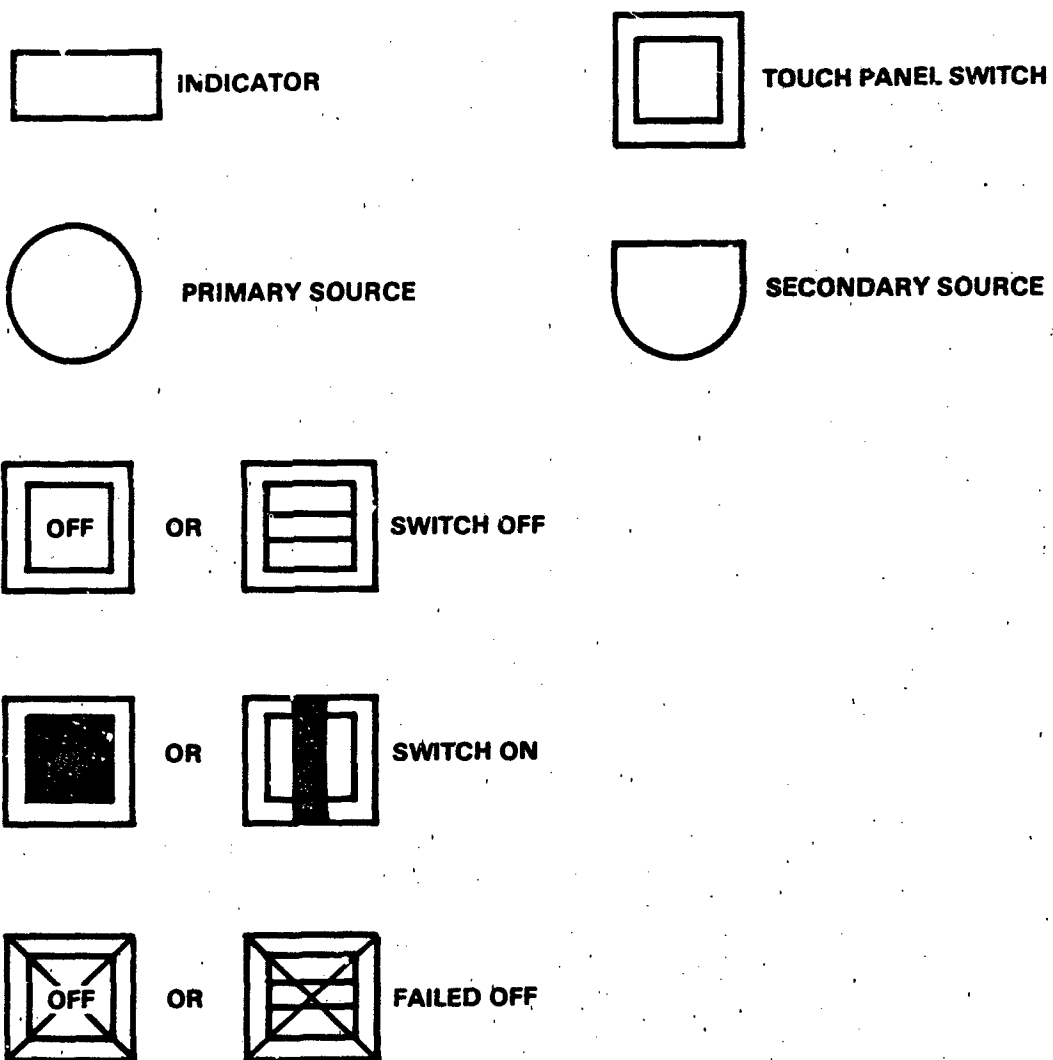


Figure 2.2.2.1-2 Example Functional System Symbolology (Garton, 1983)

information, in addition to the conventional annunciation and control devices. Appendix A contains a description of ECAM operation.

In an unpublished report, Boeing documented empirical and subjective data from an evaluation of an Advanced Systems Monitor (ASM) conducted in 1975. The ASM was proposed to be a versatile method of acquiring, managing, and displaying information concerning the status of aircraft operating systems. For the test, the conventional dial type engine and propulsion instruments were removed from the center instrument panel of a 737 simulator and replaced with two side-by-side CRTs which displayed the required systems data. A control-display unit was used to (1) display the status of the various aircraft systems, (2) manually select the system format or checklist to be displayed on the CRT, (3) insert flight data information for computation and display, (4) perform item-by-item checklist accomplishment and, (5) remove unneeded displays from the CRT. Each CRT was divided into upper and lower display sections. For normal operations the captain's CRT upper-half showed engine data; the first officer's upper-half showed systems information. The lower-half of each CRT could be used to manually display system formats or checklists at the crew's discretion or for automatic emergency checklist display. The report concluded that, overall, the ASM improved cockpit operations. The improvements were primarily associated with checklist utilizations. Since the improvements were small and primarily attributable to this one feature of the ASM, it remained questionable whether a "full blown" ASM was justifiable in new aircraft or whether just certain elements, such as semi-automated checklists, should be implemented.

Gallon and Currin, 1984 developed a Multifunction Display (MFD) System for future commercial transport aircraft. The MFD presents engine parameters, alert lists, abnormal procedures, aircraft limitations, system schematics associated with the procedures, and normal flight phase information.

Alternative designs for a CRT display system were evaluated. The recommended configuration uses two 8" x 8" CRTs arranged side by side (see Figure 2.2.2.1-3). These displays are driven by the flight warning

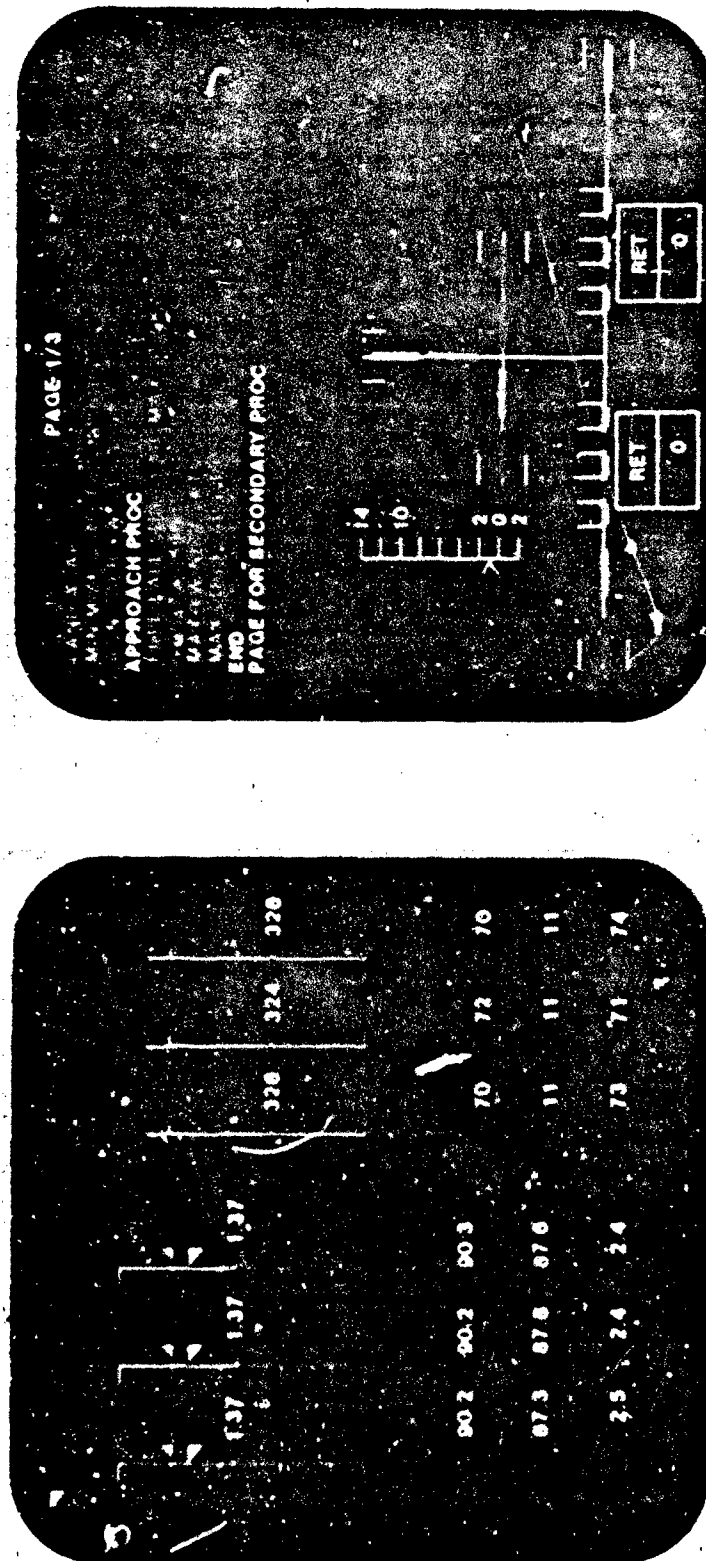


Figure 2.2.2.1-3 MFD Primary Procedure and Status Display (Gallon and Currin, 1984)

computer and have an associated control panel. System control and limited system status information is provided by the overhead panel. A warning annunciator panel is provided in case of MFD failure. During normal operation, the left CRT displays the primary engine parameters in analog form and the secondary parameters digitally. The right display provides a dedicated area for alerts, a listing of temporarily used memo functions, and flight phase information. There are five flight phase formats, which contain a mixture of alphanumeric and pictorial information.

An example of the cruise flight phase is shown in Figure 2.2.2.1-4. A description of MFD operation is provided in Appendix A.

2.2.2.2 Schematic Diagrams

Summers and Erickson (1982) developed design principles and guidelines for a multifunction electronic display system which would be used to monitor and manage aircraft systems. The intent was to identify crew actions and information requirements via a systems engineering approach. A model of the crew functions for normal and abnormal operations of the aircraft systems was developed. Task flow diagrams of the crew functions were derived using the model. From these task flow diagrams, the information requirements to perform the functions were identified. The information was categorized into the following classes:

- 1) Identifiers - The identity and the location of a component or a control.
- 2) Descriptors - The description of a component or a system.
- 3) Status - The present status of a component or a system.
- 4) Instructions - The actions required by the crew to manage the system.

The authors suggested two formats for presenting the information to the crew: a pictorial format (such as a system schematic), or by written text. The pictorial format was a representation of a system schematic with a list of action verbs and arrows indicating the site of the actions. The written

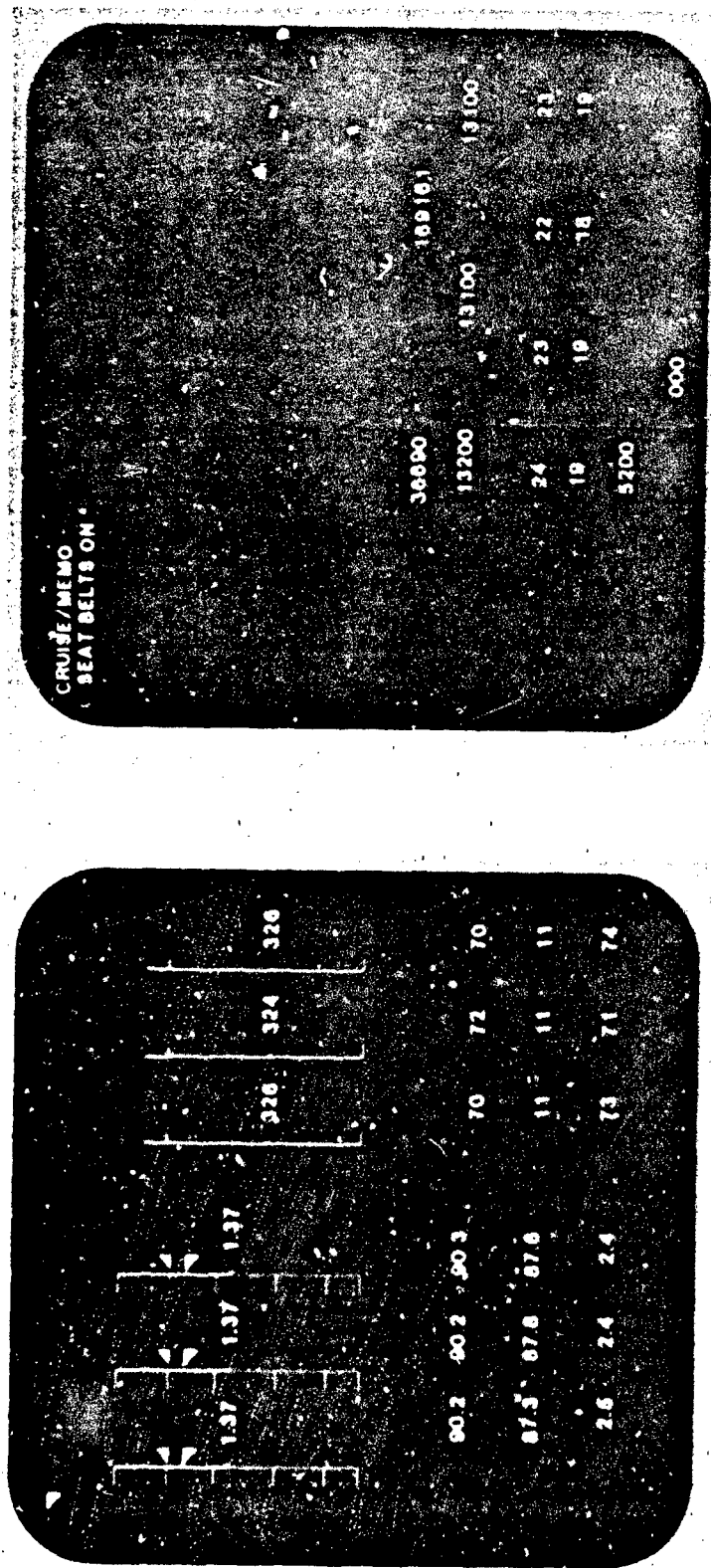


Figure 2.2.2.1-4 Example Cruise Flight Phase Format (Gallon and Currin, 1984)

text format listed the instructions by the action and the location of the action. The status of the component was listed by an identifier and the state of the component. In both formats color coding was used to indicate fault level: red for warnings, amber for cautions, cyan for advisories, and green for normal conditions. Three alternatives were given for system control: (1) dedicated system control panels, (2) a multifunction system control panel, and (3) a touch panel that would overlay the system information display. The authors proposed an empirical evaluation of these concepts by flight simulation with both normal and abnormal flight scenarios. To date, these evaluations have not been completed.

2.2.2.3 Touch Panel Systems

Gartner and Holzhauzen (1979) listed the following ergonomic problems and areas of improvement associated with the use of touch panels:

| <u>Ergonomic Problems</u> | <u>Areas for Improvement</u> |
|---|---|
| o Virtual switch size | o Improved operator training and feedback necessary |
| o Distance between virtual switches | o Unexpected delays in system acknowledgement may lead to frustration |
| o Number and arrangement of switches for various applications | o Distance, angle, brightness, and contrast must be alterable under different lighting conditions |
| o Switch shape | o Problems may exist with integrating touch panels into the existing system |
| o Switch color | o More work is needed on the menu-hierarchy progression of prompting sequences on the display. |
| o Type of feedback | |
| o Menu-hierarchy structuring | |

Pfauth and Priest (1981) presented a comprehensive report on touch panel technologies, where they listed the following advantages and disadvantages:

Advantages

- o Input/output in one location
- o Fast data entry and control for certain tasks
- o Minimal amount training required
- o Only valid options available
- o High operator acceptance
- o Immediate feedback
- o Symbolic/graphical representation
- o Minimal operator memorization required
- o Minimal eye-hand coordination

Disadvantages

- o Initial cost
- o Increased programming time
- o Need keyboard for some types of input
- o Parallax problem affecting touch locations
- o Glare
- o Fatigue
- o Finger/arm visually blocking other control-display areas
- o New method required for programming interface software

Pfauth and Priest also mentioned that touch screen devices are generally used for gross resolution tasks. The technology exists to implement these devices for fine resolution applications, but to date no one has studied the possibilities. In aircraft applications, vibration is an important element in the design of a touch panel system. Several factors were deemed important by Pfauth and Priest in the acceptance of a touch system, the most pertinent being the acceptance of such a system in high stress environments. Some design considerations are listed in Appendix A.

Colorgraphics and touch panel overlays were the topic of a paper by Conquest (1983) with regard to Automatic Test Equipment (ATE). Conquest developed a model to assess several aspects of the system including: human

factors concepts, system components, touch panel concepts, and applications. Personnel of various skill levels used the model to provide feedback on the usability of this particular type of interface. Conquest mentioned that a colorgraphic display could be understood faster than a conventional monochromatic/alphanumeric display. He also listed two advantages to using a touch panel overlay with such a display: (1) operator error rate is lowered because the system would be able to understand inputs more easily (only acceptable inputs would be available), and (2) a lower operator skill level would be required for complex tasks (graphics would be easy to decipher).

Under "Human Factors Concepts," the layout of display items was discussed. Dedicated areas were provided for commands, graphics, and for "softkeys", touch control keys which can be re-programmed for various applications. The only softkeys not included in the dedicated control area were those used for station mode changes.

System components include size and resolution of the display, and overlay type. To meet high resolution touch panel requirements, Conquest stated that a transparent resistive CRT overlay should be used. Other technologies (such as capacitive and infrared) cannot reach the resolution accuracy provided by the resistive touch panel. However, there are some disadvantages to using a resistive touch panel. Because of the resistive substrate, the panel blocks a portion of the CRT light output. Also, the extra surface adds to the reflection of incident light, therefore special considerations need to be made when designing a system for use in widely varying lighting conditions (such as aircraft cockpits).

The "softkey" concept was the primary touch panel concept described. The size and placement of the keys on the display is constant; only the functionality varies. There are two advantages to such a system: (1) the softkeys remain in the same area on the screen (consistency of placement), and (2) softkeys can be easily programmed for various applications. Some critical factors exist with respect to the design of a softkey concept. One is the alignment of the panel responses with the display area. After a

functional change has been made to a softkey, it is imperative that only the appropriate key locations be operational, meaning that a valid key should provide the desired system response, and an invalid key should be ignored. Another factor to consider is size of the keys, as well as spacing between keys. Amount of space consumed by each key must be weighed against the ease of hitting a displayed key. The parallax problem encountered with some types of touch panels is also mentioned as a factor. Feedback is another important concept, with a burst of audio being the recommended feedback after touching a valid softkey.

Several applications of colorgraphics and touch panels are discussed by Conquest, such as:

1. The operator can be led through a set of decision points graphically when testing a faulted unit.
2. The interface can display graphically what to adjust or look for on the unit under test.
3. A fault can be isolated via a graphic representation of the unit under test.

In his conclusion, Conquest summarizes the advantages of the softkey concept; lower error rates, lower skill level required, "natural" data input by use of the finger, elimination of confusing keyboards, and versatility in applications.

2.2.2.4 Voice Input Systems

In a 1983 report, Steiner, Burkhart, and Berson discussed Automatic Speech Technology (AST), a combination of word recognition and speech synthesis. They compiled the following list of advantages and disadvantages:

Advantages

- o Natural form of communication - requires little training.

Disadvantages

- o Reliability questionable with environmental noise and vibration.

Advantages (Cont.)

- o Faster and more accurate than keyboard data entry when eyes and hands are busy.
- o Freedom of movement given to operator.
- o Simultaneous communication possible with machines and other humans.
- o Serves as form of identification.
- o Increased communication capability may be useful in time-critical situations.

Disadvantages (Cont.)

- o Voice input error detection and correction "not fully defined".
- o Correcting recognition errors may lead to other errors which in turn may be frustrating.
- o Necessity to pause between utterances can cause frustration.
- o Messages could interfere with other operations (i.e., radio).
- o Inter-individual and intra-individual differences could affect recognition system operability.
- o Limited vocabulary available.
- o Large storage facility necessary for large vocabulary.
- o Keyboard data entry faster for simple tasks.
- o For speech synthesis: rate of receiving auditory messages slower than receiving visual messages.

Steiner, Burkhart, and Berson concluded that systems which require complex and simultaneous tasks could benefit from AST; thus, voice technology would be a viable mechanism to provide guidance and feedback during an emergency situation.

Simpson (1982) found that speech input/output controls can reduce helicopter pilots' workload during missions where the eyes and hands are busy.

Costet (1982) studied single seat fighter aircraft. During simulator tests, a synthesized voice using a vocabulary of approximately 60 words was used to describe manual controls. This allowed a comparison between manual and vocal controls. It was discovered that: (1) voice input/output reduced pilot workload and resulted in a time savings, (2) practice with the system improved recognition accuracy to 95%, and (3) an ON/OFF microphone switch was necessary to distinguish the voice input/output commands from ambient noise.

Steiner, Burkhart, and Berson compared visual vs. voice vs. a combination of visual and voice feedback during a simulated voice activated weapon launch sequence. To insure that subjects attended to the feedback, incorrect feedback was presented approximately one-third of the time, and subjects were instructed to say "CANCEL" at such a time. Visual stimuli (prompts) were presented on a terminal, and the visual feedback (when presented) appeared next to the prompts. The basic results of their study were:

1. Reaction time was lower with a combination of visual and vocal feedback, as opposed to either visual or vocal feedback alone.
2. Number of errors was also lessened with both visual and vocal feedback.

The authors concluded that both auditory and visual feedback should be provided to enable the operator to select feedback modality based upon present operational demands.

In conclusion, it appears that voice input/output is an appropriate guidance and feedback tool in complex situations (such as aircraft emergencies). Consideration would have to be taken, though, in the implementation of the system, such as the addition of a voice control switch to lessen the possibility that ambient noise would interfere with message transmission and receipt.

2.2.2.5 Conclusion

It was hoped that the literature review would provide some insight on the utility of various concepts. As can be seen, no studies were published where implementation methods had been compared, and no standardization exists among system designs. Since no empirical results are available, the studies discussed above, in conjunction with the results from the demonstrations and results of the questionnaire, will be used to refine the FSM concepts early in Phase II.

2.3 FSM DISPLAY AND CONTROL ELEMENTS

Based upon the workshop sessions, the literature review, and a preliminary demonstration, the study team identified alternative concepts for demonstration. Four of these concepts use the same display formats, but differ in the method of display and system control. A fifth concept uses a display scratchpad with a programmable multifunction keyboard, and another concept is an automatic reconfiguration of the system. A synopsis of the features of these candidate concepts is presented in Table 2.3-1. The display and control elements of these concepts are summarized below.

2.3.1 Alert Display and FSM Controls

The alert display is a color CRT with line address keys mounted on the left and right sides. The FSM controls are mounted below the alert display as shown in Figure 2.3.1-1. The functions of the alert display have been described in Berson, et al, 1981. It displays up to eleven alerts on one page. The alerts are color coded and prioritized according to their urgency level. New alerts appear at the top of the list in their alert category.

With each alert there is a line select key. This allows selection of a particular alert by the crew which activates the row of keys at the bottom of the display. These keys allow the crew to select the procedure and status pages for the line-addressed alert by depressing the checklist and status keys. The crew can step through the procedure and status pages by

| Level of Automation | | FSM Candidate Concepts | | | | | | | | Control and display summary | | | | |
|---------------------|-----------------------------------|------------------------|--------------|--------------------|----------------|------------------------------|--------------------------|-------------|-------|-----------------------------|---------------------------|---|---|---|
| Manual | Basic | System aided | System panel | Procedures display | Status display | Procedures call-up automatic | Status call-up automatic | Touch panel | Voice | Keyboard scratch pad | Automatic Reconfiguration | | | |
| | | | X | X | X | X | X | X | X | X | X | X | X | X |
| System aided | Basic (with auto display call-up) | | X | X | X | X | X | X | X | X | X | X | X | X |
| | Touch panel interactive display | | | X | X | X | X | X | X | X | X | X | X | X |
| | Voice interactive display | | | X | X | X | X | X | X | X | X | X | X | X |
| Automatic | Multifunction keyboard | | | | X | X | X | X | X | X | X | X | X | X |
| | Automated response | | | | X | X | X | X | X | X | X | X | X | X |

Table 2.3-1 Summary of Candidate System Concepts

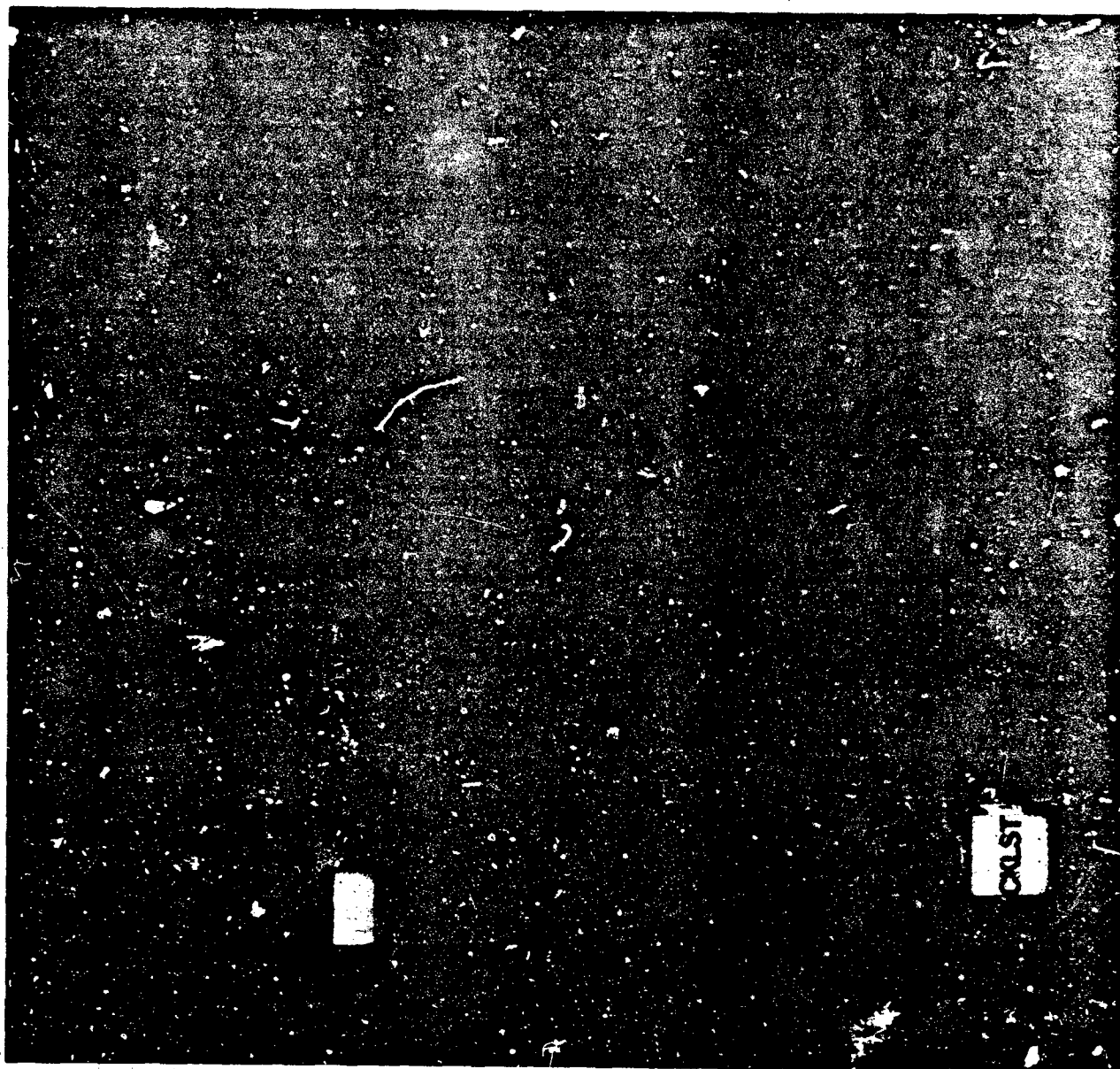


Figure 2.3.1-1 The Alert Display with FSM Controls.

multiple depressions of these keys. If an alert has been addressed and the procedures are incomplete, the store and recall keys are inhibited. Once the procedures have been completed, the procedure and status displays are cleared, and if the alerting situation no longer exists, the alert will be removed from the alert display. If the alert was in a lower urgency category than a warning, it may be stored. By depressing the recall key, stored alerts will reappear on the alert display and the crew may review the procedures and status by depressing the line select, checklist, and status keys in sequence. The page key allows the crew to page through the alert display and the voice key activates the voice system.

2.3.2 Procedures Display

Step-by-step procedures for responding to normal, abnormal, and emergency situations are presented on the procedures display in checklist format. One action item is presented per line whenever feasible, and as many action items as feasible are presented on a single page. The items requiring crew action are one color, and the completed actions are another color. As the crew completes an action the action item changes format and color. If the action is not sensed by the aircraft, the crew must acknowledge its completion, by selecting a "completed action" key, before the item changes color/format. Branching is presented by "if statements" in the action color. Once the action is sensed after a branching statement, the one alternative action is presented. If the crew fails to perform an action item and proceeds to the next action item, the uncompleted item will remain in the action color.

The actions will be listed in priority order. All actions that have an immediate effect on aircraft safety will be listed first. Cleanup procedures will follow. Procedures affecting other flight phases will follow the cleanup procedures. (Such procedures will automatically be integrated into checklists in those flight phases.) For multiple alerts, the actions will be integrated according to the priority logic established by the system. Those faults that cause subsequent faults will be listed first. If these are corrected, then the subsequent faults will disappear. In case

of independent failures, they will be listed according to their fault level and their order of occurrence.

2.3.3 Status Display

The status display will have pictorial and alphanumeric presentations. There may be as many as four pages associated with a fault:

1. A page presenting the aircraft status showing operational limits and the non-operating systems.
2. A page showing the schematic diagram of the system involved with the procedural action.
3. A page identifying the system with the primary failure.
4. A page(s) presenting any additional, operational information that is currently contained in operations and flight manuals.

The first status page will show aircraft status, including degraded systems and operating limits. The second page will display a diagram of the procedural action site. The third page will show a diagram of the system or subsystem containing the failure which generated the alert. The fourth page will display information pertinent to flight operations as a result of the failure/ alerting situation.

System status will be shown by simplified system schematics. These schematics will show system flow by interconnecting lines and identify different components by symbol shapes. Color coding will be used to indicate operating and fault status. For example, unfilled symbols could indicate "OFF" status and a filled symbol could indicate "ON" status. Alphanumerics will be used to identify the components and for presenting quantitative parameter values when required.

Aircraft status will be shown by a simplified pictorial of an aircraft (e.g., a plan view outline of the aircraft). Symbols will be used as much as possible for the faulted systems. Other information will be presented by alphanumerics. Failed components will be color coded according to fault level (e.g., red or amber).

2.3.4 System Control

Several alternatives have been selected for control of the aircraft systems in conjunction with the FSM. These include:

1. System Control Panels - System control panels are located either at a flight engineers station or in the overhead panel. The aircraft systems are controlled with the systems panel which is not part of the FSM. However, information feedback on the status of the controls and the operation of the system is provided by the FSM.
2. Touch Panel Control - The touch panel overlaying the status display allows system control to be next to the displayed procedures. The touch panel allows the crew to perform the action item by touching the display. Feedback information is presented on both the procedures and status displays, and the crew's attention is focused on only these two displays for completing the procedure.
3. Voice Interactive Control - Voice commands are used to call up and control the displays and the aircraft systems. The voice system is activated by depressing the FSM VOICE key. After activation, the crew is able to call up and perform the action items.
4. Multifunction Keyboard - The multifunction keyboard is configured with programmable legend keys. The first key lists the first action item from the procedures display. The second action item is listed on the second multifunction key, and so on. To perform the action item all the pilot has to do is depress the corresponding multifunction key.

2.4 CANDIDATE CONCEPTS

The FSM concepts differ in their level of automation: manual, system aided and automatic. With the manual method, aircraft system reconfiguration is accomplished on the systems overhead panel. The system aided concepts include automatic display callup, and the aircraft systems are controlled by innovative concepts in conjunction with the FSM displays including voice interaction, touch panel overlays, and a multifunction keyboard. The last concept is automatic reconfiguration which only requires the crew to give a go-ahead signal. This concept may be used in conjunction with any of the

above concepts, but for this study it was implemented only in the multi-function keyboard concept. In all of the concepts, feedback information is provided on both the procedures and status displays.

2.4.1 Basic Concept

The operation of the Basic concept is shown in Figure 2.4.1-1. After an alert occurs, the crew cancels the master caution and warning indicator and reads the alert display to identify the fault. By pushing the line select and CHECKLIST keys, the alert procedure is displayed on the procedures display. If the crew pushes the STATUS key, the aircraft status is presented on the status display. By selecting the STATUS key again, the FSM will display the system schematic associated with the first procedural action item.

The crew reads the checklist and performs the necessary actions on the overhead panel. If there is more than one page of procedures, the completion of the items on the first page will bring up the next page. By repeated pushing of the CHECKLIST key, the crew may step through the procedure pages. After the procedures are completed, the crew may step through the status pages by pushing the STATUS key. After completion of the checklist procedures, the displays will be cleared. The alert message is removed from the alert display if the alerting situation no longer exists, otherwise it may be cleared by line selecting the alert and selecting STORE. Selecting STORE will store all alerts, except warning level alerts and alerts which have pending checklists.

2.4.2 Basic Concept with Automatic Display

This concept is the same as the Basic concept except when the crew pushes the line select key, the procedures display and status display (aircraft status page) will be brought up automatically (see Figure 2.4.2-1). As the crew completes all the procedures on a page, the next page will appear automatically. After the procedures are completed, the crew may step through the remaining status pages.

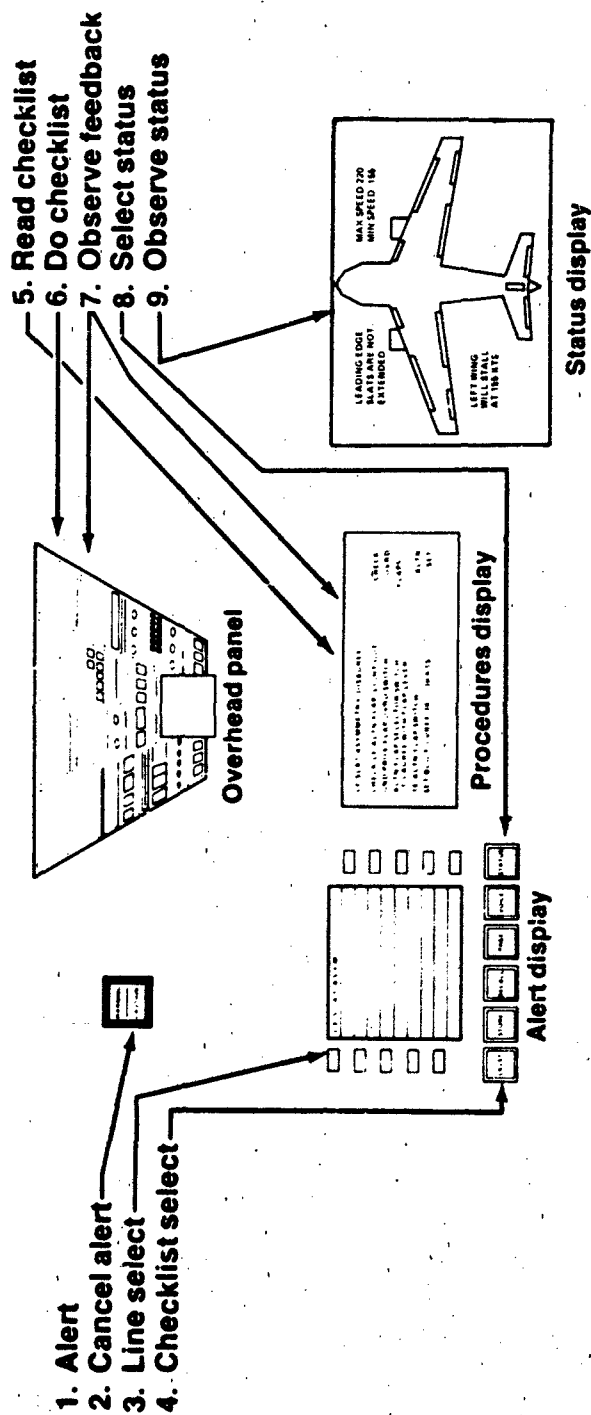


Figure 2.4.1-1 The Basic Concept

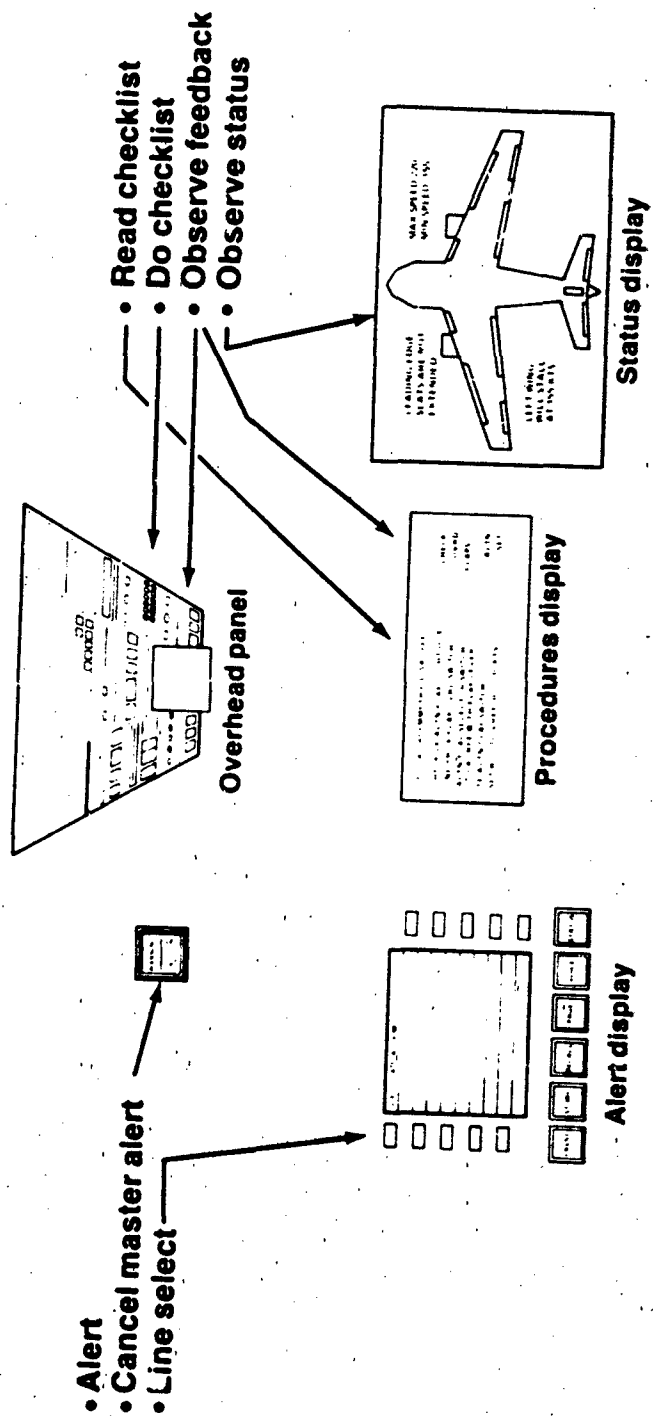


Figure 2.4.2-1 The Basic Concept (with Auto Display Call-Up)

2.4.3 Touch Panel Interactive Concept

This concept is illustrated in Figure 2.4.3-1. The procedures display and status display (aircraft status page) are automatically called up by the pilot selecting the line address key on the alert display. The pilot performs the actions directly on the status display. After manually stepping past the aircraft status page, the status display will contain a schematic, related to the first action-item, with computer generated touch keys to reconfigure the system. Feedback information is presented on both the procedures and status displays. Each action item will have a corresponding schematic diagram on the status display. This display is also touch interactive for calling up more detailed information, if desired.

2.4.4 Voice Interactive Concept

This concept, shown in Figure 2.4.4-1, uses voice for both messages and control of the displays and aircraft systems. Voice control actuation is optional, and both the displays and systems may be manually controlled as described under the Basic or Touch Interactive concepts. Voice messages are used to direct the crew's attention to alerts and to the actions to be performed if the alert is a time-critical alert.

After pushing the line select key, the pilot may select voice interaction by depressing the VOICE key. When the displays are called up, the first action item would be addressed. To execute an action item, the crew says, for example, "PUMP 1 OFF" and an execution command, and the action is completed. The crew continues this process until all the procedures are completed. Feedback is presented visually on the procedures and status displays and may be presented by voice messages.

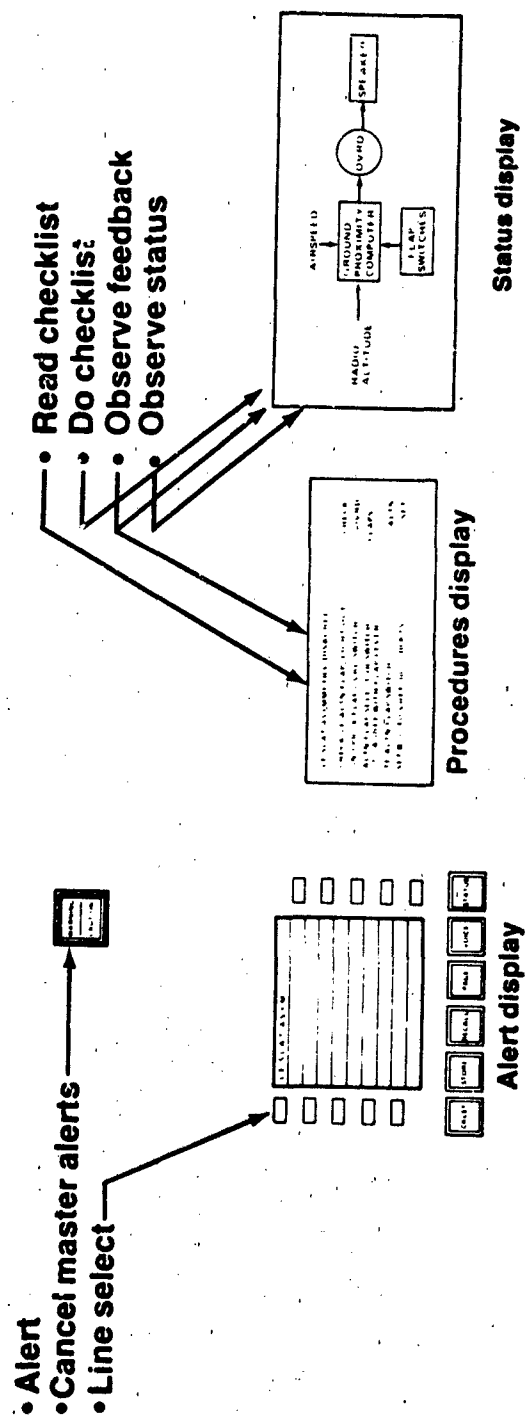


Figure 2.4.3-1 The Touch Panel Interactive Display

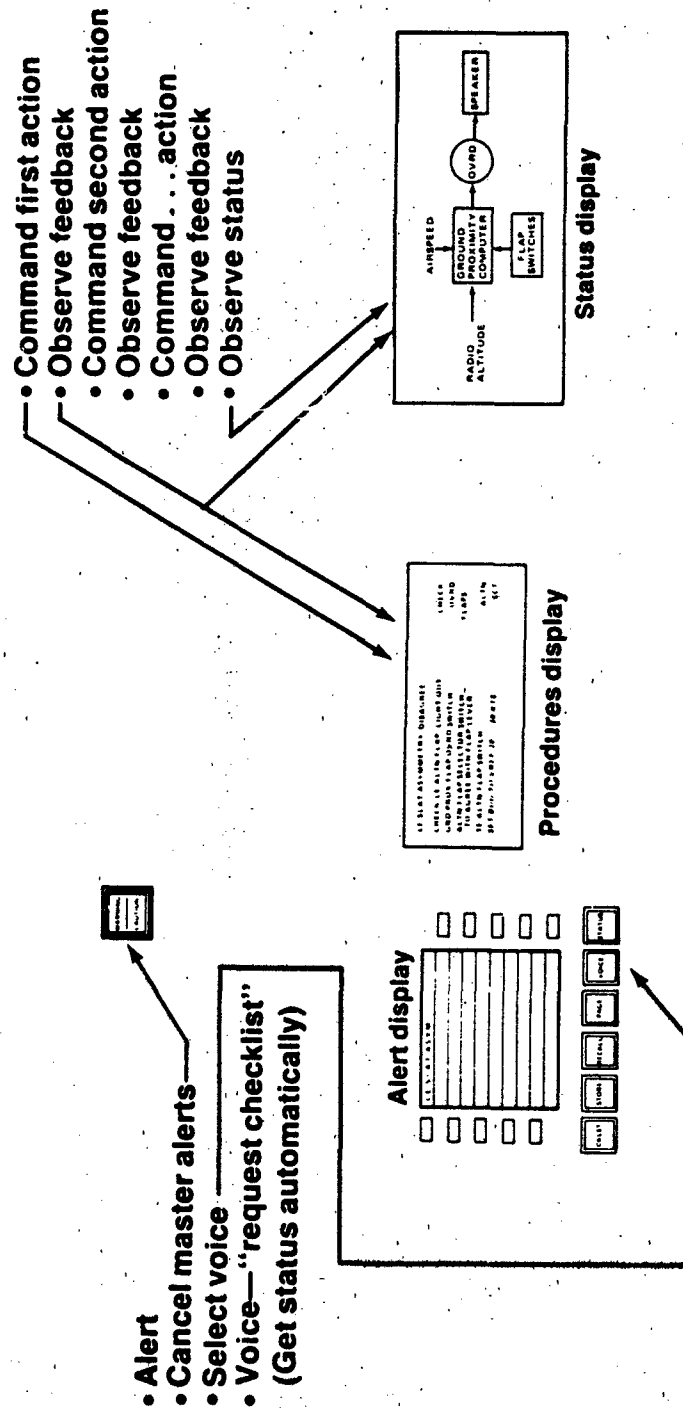


Figure 2.4.4-1 The Voice Interactive Display Concept

2.4.5 Multifunction Keyboard Concept

This concept uses a multifunction keyboard with programmable keys and a scratchpad. The scratchpad display presents the alert procedures. Aircraft status, system diagrams, and operational information are shown on the status display as in the other concepts. The multifunction keyboard presents the sequence of control actions by having the legends on the keys correspond with the action items on the checklist. This concept has also been termed "Directed Selection" because of this capability to present the sequence of actions to be taken by the crew.

The operation, as illustrated in Figure 2.4.5-1, shows that after line selecting the alert, the checklist appears on the scratchpad, and the actions that are interactive with the aircraft systems are presented in sequence on the multilegend keyboard. To perform the action items, the pilot must depress the corresponding multifunction key. To perform actions that are not interactive with the aircraft systems, such as "CHECK air-speed" and SET altimeters", the pilot does the action and then indicates to the system that the action has been accomplished by selecting a dedicated button labeled DONE. This procedure is continued until all items are completed. Feedback is provided on the scratchpad, on the multifunction legends, and on the status display. The operation of the checklist on the scratchpad is the same as on the procedures display used in the other concepts.

2.4.6 Automatic Reconfiguration Concept

Any of the systems-aided concepts could incorporate pilot-initiated automatic system reconfiguration. For demonstration purposes, the multifunction keyboard concept was used to evaluate the feasibility of this control method. This concept requires the same steps to call up the checklist on the scratchpad display and the procedural steps on the keyboard. However,

the crew has only to select one key, a dedicated key labeled EXECute, to initiate the corrective action. The system automatically does the action items that are interactive with the aircraft systems, at a predetermined rate, stopping at items that must be accomplished by the pilot. Action and status feedback are presented on the status and scratchpad displays (Figure 2.4.6-1). The crew has the option to stop the reconfiguration at any time.

3.0 SCENARIO DEVELOPMENT

3.1 OBJECTIVE

The primary objective for the simulated flight scenarios is to provide a realistic test situation for use in evaluating FSM system candidate concepts. The flight scenarios must realistically task the pilot so meaningful data can be obtained.

3.2 APPROACH

Several qualifications were made when designing the scenarios. First, it is necessary that the system failures and the adverse operational situations, which are the bases for the alerts, can be sensed via the aircraft and its associated sensor system.

Second, it is necessary that the alerts selected and the sequence of events are appropriate, since the basic purpose of the study is to demonstrate/ evaluate the functions of a flight status monitor. Not all pilots will experience every alert up to the time-critical situation. Some pilots will accommodate for the degrading situation early in the scenario and never experience a high level alert. However, the system should be designed to provide continuous monitoring of flight conditions from simple situations up through degraded or compounded situations.

Scenario development was accomplished in three steps. First, alerts identified in Phase IV which have the potential for improving aircraft safety were selected. Second, candidate system concepts to handle the alerts and present them to the crew had to have been developed. Third, simulated flight scenarios were designed which would present the alerts in a realistic flight operation.

Alert selection has been a continuing process. The survey of accidents in Phase IV produced a list of alerts which appear to have potential benefit

for improving aircraft safety. The study showed that when crew error was a primary cause, approximately 6% of the accidents resulted from navigation errors. Therefore, navigation error was selected as an alert candidate to be provided by the FSM. Similarly, other alerts were derived in Phase IV, including:

- o WIND/WINDSHEAR
- o TIRE/WHEEL FAILURE
- o COLLISION AVOIDANCE
- o TAKEOFF ABORT

Outside sources suggested other alerts for the list or supported those already on the list. For example, the FAA suggested an alert for differential lift across an aircraft's wings. Safety experts proposed the use of tire failure and/or insufficient acceleration as the basis for a takeoff abort alert. The recent reporting of incidents caused by fuel shortage prompted the consideration for a low fuel alert.

Low-level alerts were then selected which might indicate the early states of a degrading situation, leading up to a condition/situation which might develop into an accident. For example, a stall might be preceded by a wing asymmetry alert, and an abort might be preceded by an alert for low acceleration.

The list of the alerts considered is provided below:

- o DIFFERENTIAL LIFT
- o ABORT
- o TIRE FAILURE
- o NAVIGATION ERROR
- o LOW FUEL
- o INSUFFICIENT BRAKING
- o COLLISION AVOIDANCE
- o WINDSHEAR
- o GROUND PROX
- o STALL
- o WING ASSYMMETRY
- o LOW ACCELERATION
- o ENGINE ANTI-ICE
- o ENGINE VIBRATION

3.3 SCENARIO DESIGN

Three simulated flight scenarios were developed to evaluate the preliminary FSM concepts, they are:

1. Differential Lift - An approach in bad weather with a sequence of events which lead up to a differential lift and stall situation.
2. Takeoff Abort - A take-off situation in which the aircraft fails to achieve sufficient acceleration and the system signals an abort alert.
3. Navigation - An enroute cruise situation in which navigation errors and multiple system failures occur.

3.3.1 Differential Lift Scenario

This scenario is built around the critical flight conditions of differential lift. The pilot's concern is to avoid stalling a wing. Therefore, the highest urgency-level alert in the scenario is "STALL".

To provide a degree of realism for the system demonstration, the scenario has included several alerts which might be pre-cursors to a wing stall. Those selected, in order of their occurrence are:

| <u>Alert</u> | <u>Assigned Urgency Level</u> |
|------------------------------|-------------------------------|
| Left engine anti-ice failure | Caution |
| Left engine vibration | Caution |
| Left engine shutdown | Caution |
| Leading edge slats asymmetry | Caution |
| Wing stall | Warning |
| Stall | Time-Critical |

Normally, engine anti-ice failure is only an advisory-level alert, but the FSM has in its data file that icing conditions exist so it elevates the alert level to caution.

These alerts are woven into a theoretical flight from Chicago to Boston in adverse weather. Enroute to Boston the crew is told to hold for traffic metering and must change landing runway because of a wind shift. Task workload is provided by the combination of the ATC communications, the landing runway change, the flight control difficulties due to the bad weather with light turbulence, and the sequence of failures. Figure 3.3.1-1 shows a simplified profile of this simulated flight scenario.

3.3.2 Takeoff Abort Scenario

This scenario demonstrates how the FSM could be used to aid the pilot in the critical takeoff flight phase. It is generally considered that takeoff is more demanding on the aircraft than on the pilot. The pilot has two tasks: to decide to continue the takeoff and to guide the aircraft into the air. However, because of the many factors in the decision process and the time-criticality of the decision, computer-aided decision-making by the FSM could aid pilot performance.

The scenario shown in Figure 3.3.2-1 will be a short sequence of events, during a flight's departure, which will lead to a takeoff abort alert. Several conditions will be set in the simulator which will hinder normal acceleration. These include: simulation of snow and slush on the runway, low tire inflation, up slope of the runway, and a heavy aircraft. During this scenario, the pilot could fail to set full takeoff thrust and be slow in deciding to abort. It is anticipated that these conditions, coupled with the weather and delayed decisions may lead to the FSM calling for an abort. Precursor alerts for low acceleration will be provided at the advisory, caution, and warning levels before the time-critical abort alert is presented. If the pilot cannot correct for the lower level alerts, he would probably abort the takeoff before the abort alert is given. While this would be less dramatic, it will still demonstrate the system capability to aid the pilot by providing guidance for this potentially critical situation.

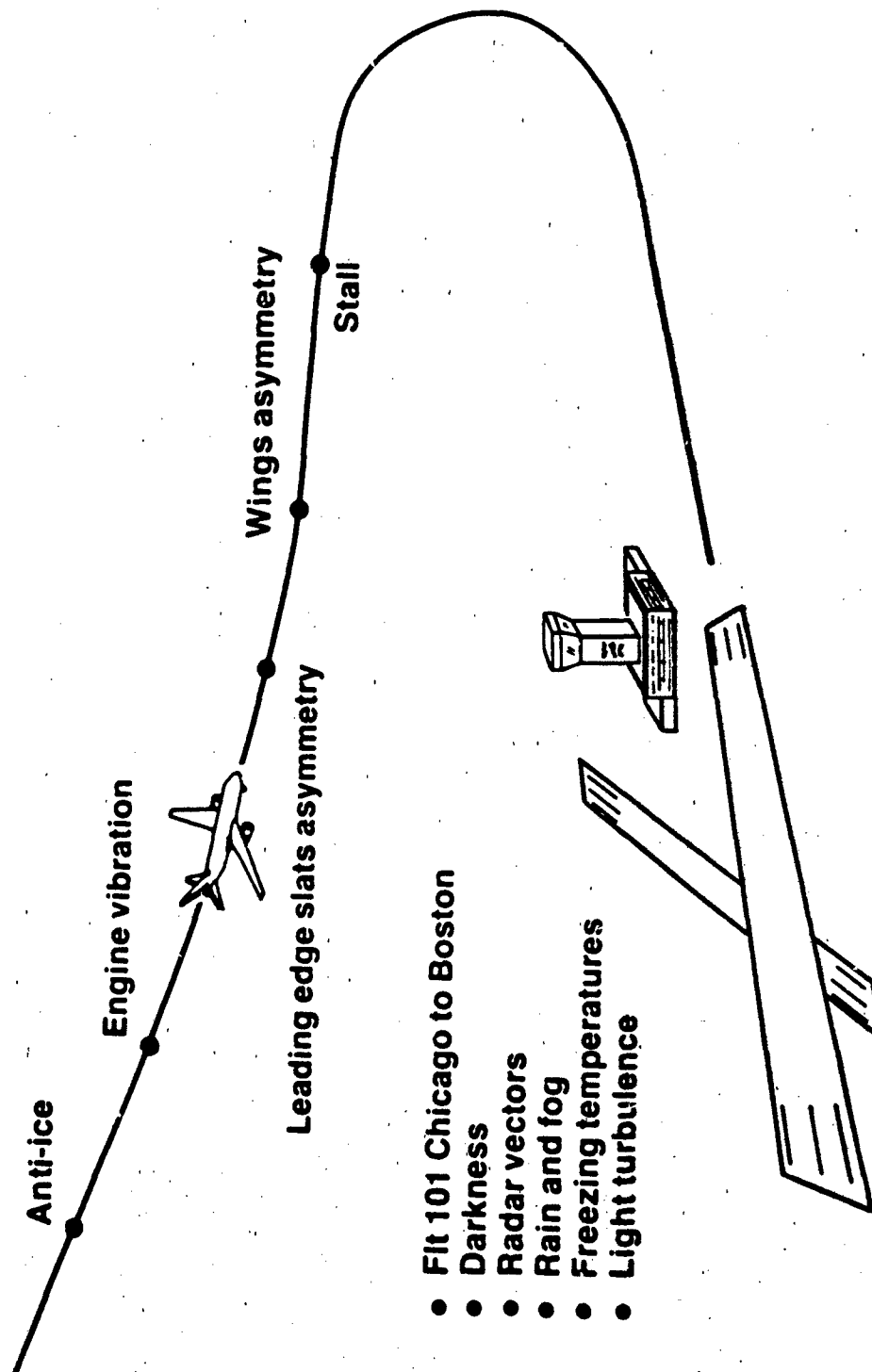


Figure 3.3.1-1 Differential Lift Scenario

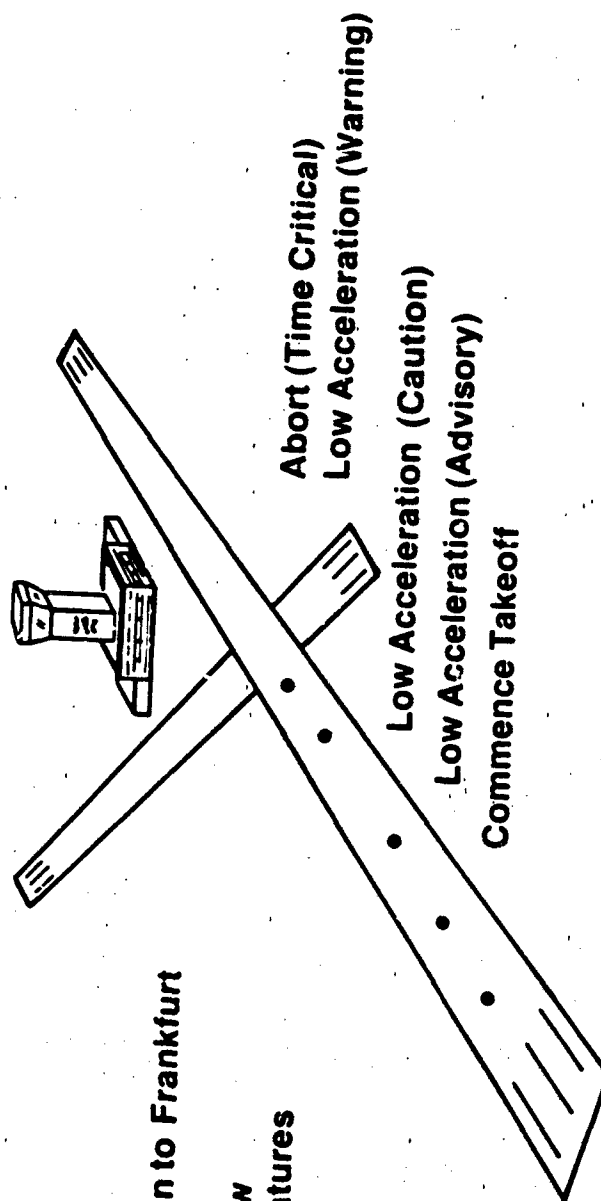


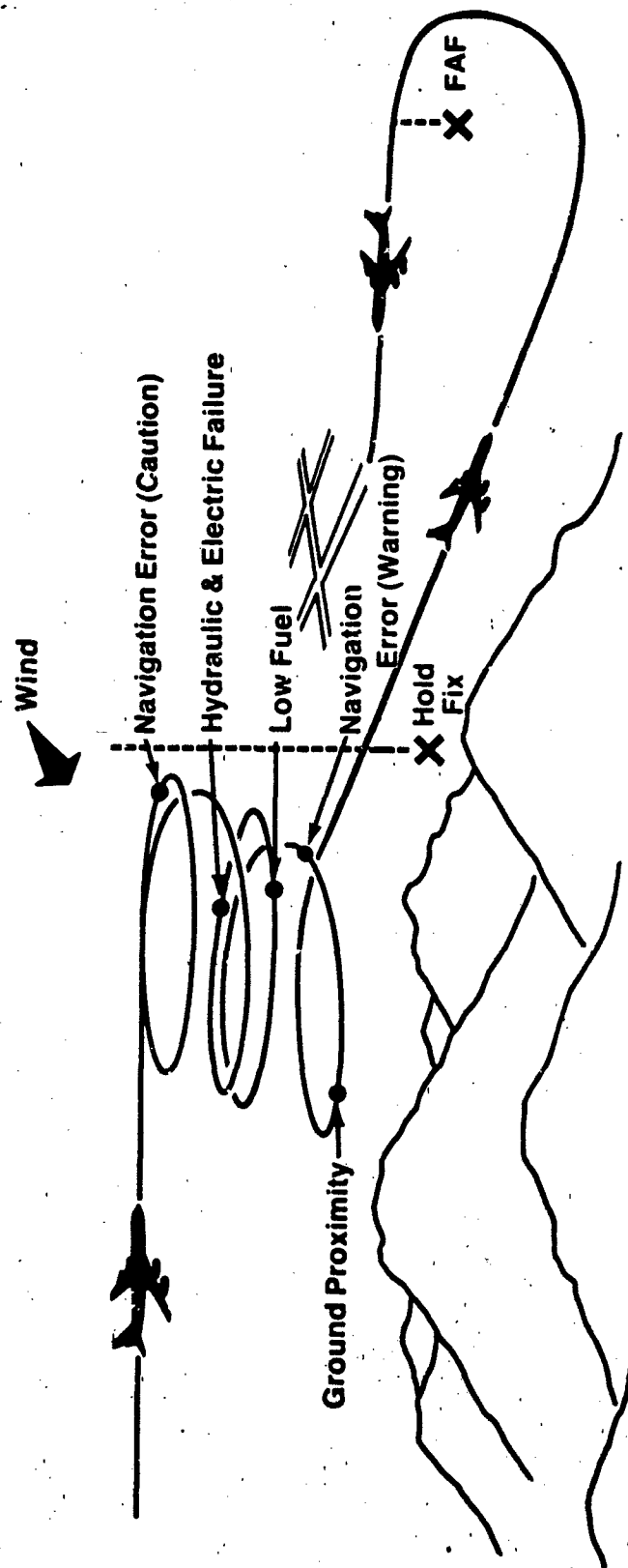
Figure 3.3.2-1 Takeoff Abort Scenario

3.3.3 Navigation Error Scenario

This scenario will be a sequence of events which may lead to a ground proximity time-critical alert. The scenario will include a multiple alert situation to demonstrate the capability of the FSM to handle these complex and often critical situations. Two system failures, a hydraulic and an electrical failure, will be initiated. The FSM will prioritize the two sets of procedures and integrate them into a single procedure for the pilot to handle.

A predictive low fuel alert will be included in the scenario to demonstrate the potential for the use of "expert systems" in the design of the FSM. It is intended to take advantage of the capabilities of knowledge-based systems and the ever-increasing amount of microprocessor-based information that is available on the aircraft. The use of expert systems addresses many of the requirements for future crew alerting systems as suggested in Phase IV, such as a greater number of sensor inputs, greater flexibility, the need to handle multiple anomalous events, and the need to respond to specifics of the various flight phases.

The navigation error scenario is illustrated in Figure 3.3.3-1. The simulated flight depicts the final legs of a flight from Phoenix to Salt Lake City, in darkness and frontal weather. To impose a high pilot workload, frontal weather with turbulence, wind shifts, and darkness will be simulated. The pilot will also handle flying duties as well as comply with ATC communications and holding requirements. Multiple system failures will occur. It is anticipated that the pilots might drift off course causing a low level navigation error alert. Some pilots may also receive an alert for a major navigation error. For some pilots, the navigation will degrade until a ground proximity time-critical alert is triggered.



- Flt 101 Phoenix to Salt Lake
- Darkness
- IFR Conditions
- Frontal Weather
- Light Turbulence

4.0 DEMONSTRATION PLAN

4.1 OBJECTIVE

The objective of the demonstrations was to obtain feedback and comments from pilots and engineers to refine the preliminary FSM concepts. Feedback obtained from these demonstrations will be the major source of information for refining the candidate concepts to be evaluated in Phase II.

4.2 APPROACH

Two concept demonstrations were conducted in Phase I. In the first demonstration, the study team members and the FAA contract monitor reviewed the initial set of FSM functions implemented in the simulator. In the second demonstration, six pilots were led through the Differential Lift scenario. For this demonstration both the Basic and Basic with Automatic Display concepts were implemented in the simulator. In addition, the system-aided and automated concepts were discussed to obtain pilot comments and feedback.

Additional team demonstrations will be conducted early in Phase II, after the system-aided/automated concepts are implemented in the simulator. With the demonstrations, the FSM concept/design issue questionnaire will be administered to validate its design. The questionnaire is contained in Appendix B.

4.3 SIMULATION FACILITIES

4.3.1 Mock-up and Integration Laboratory

The Mock-up and Integration Laboratory at the Boeing Commercial Airplane Company's Development Center was used to develop and demonstrate the FSM concepts (see Figure 4.3.1-1).

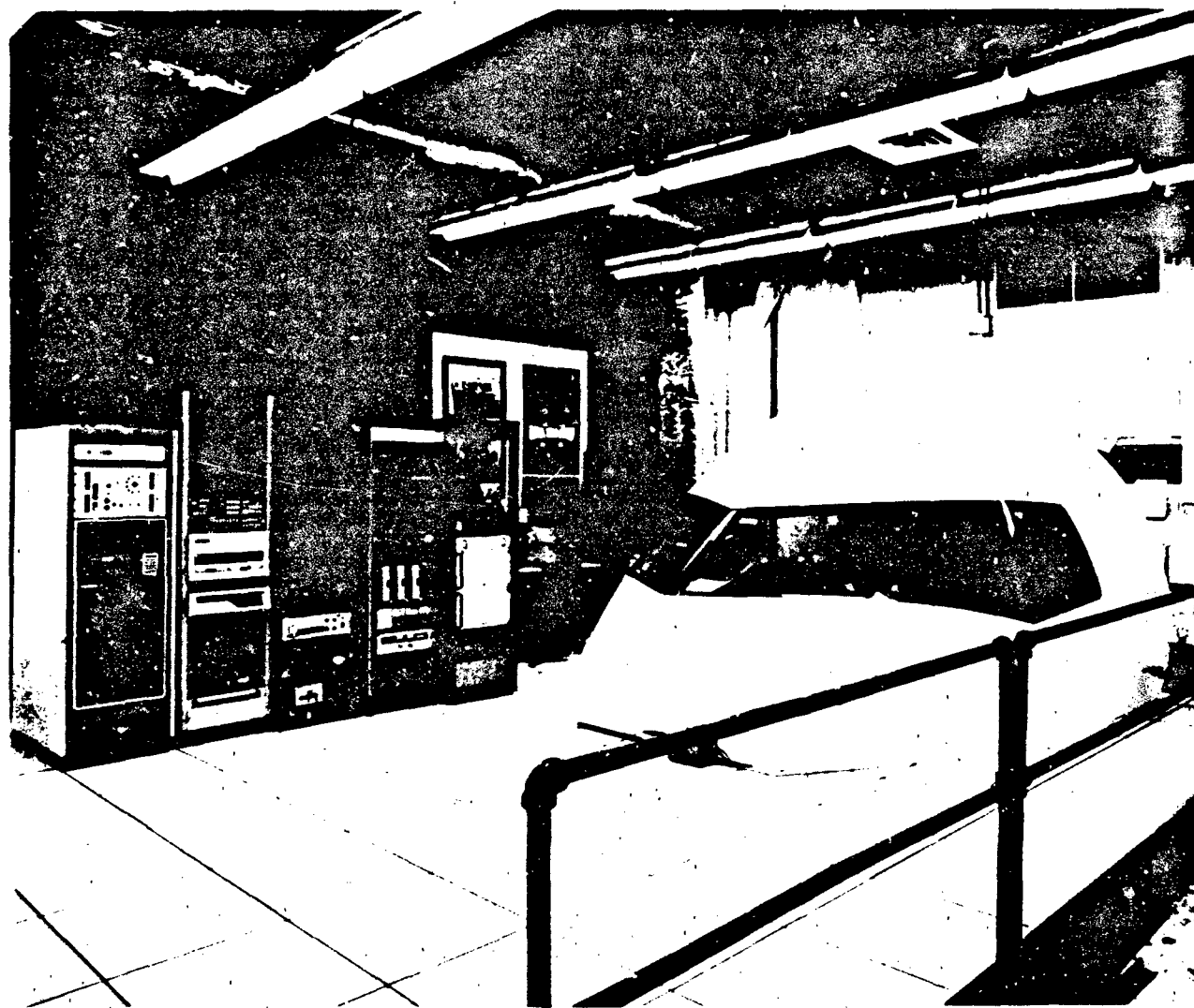


Figure 4.3.1-1 Mock-Up and Integration Laboratory

The Mock-up and Integration Laboratory provides R & D capability for developing advanced flight decks. The laboratory is used for: (1) early laboratory work requiring use of bench development and test facilities, (2) successive stages of part task simulation using simplified approximations of sensor and aircraft systems, and (3) concept implementation in a cockpit simulator to confirm appropriateness of interface provisions and operations before flight test.

4.3.2 Research Cab

The center of the lab is a new generic widebody fiberglass aircraft cockpit. The cab has been designed to be easily reconfigurable and can be configured for two or three (forward facing) crew members. All the displays, their control panels, mode switches, control display units and flight controls are mounted in the cab.

The cab serves a dual purpose. First, it provides a facility to appraise the requirements for an individual display or control, including the display content and format. Secondly, the cab provides the capability to perform system integration work to support the development of new display or control systems.

The cab is equipped with state-of-the-art color displays. Figure 4.3.2-1 shows the flight deck with the EADI and EHSI surrounded by four CRTs presenting secondary instrument information. The center instrument panel contains four CRTs, two of which present engine instrument data. The two CRTs, shown blank, are being used to present emergency procedures and status information for the FSM.

Figure 4.3.2-2 shows the cab displays which will be used for the FSM demonstrations. On the left is the visual information display, also called the alert display or alphanumeric display. The displays to the right of the alert display are the procedures and status displays, respectively.



Figure 4.3.2-1 The Research Cab

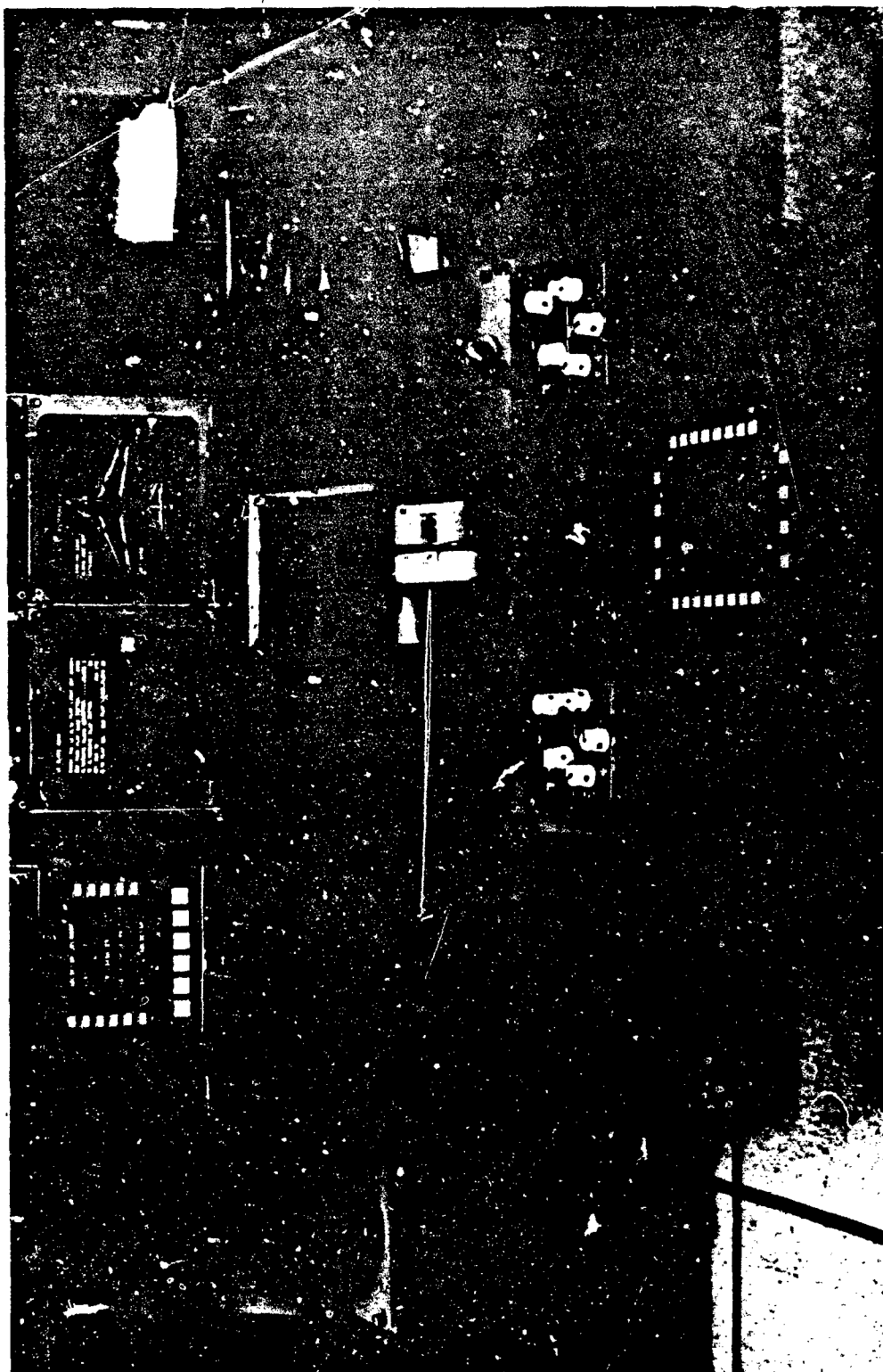


Figure 4.3.2-2 Flight Status Monitor Displays

At the bottom of the picture, on the center aisle stand is the system action panel with its 15 programmable keys. During test, this panel serves as a substitute for the airplane's system controls, usually located on the overhead panel. The panel also serves as the control panel for the "Multi-function Keyboard" candidate FSM concept.

The alert display uses 11 lines of 16-character alphanumerics to provide:

- o One location where all warning, caution and advisory messages are displayed
- o A concise alert message for each problem
- o Information about alert urgency
- o Some direction for crew corrective actions
- o Feedback to crew when faults are corrected
- o Line select and function selection of display formats.

The checklist/procedures display and the status/schematics display are 6 x 7 inch Collins shadow-mask CRTs. They provide a 7-color repertoire in alphanumeric or graphic format.

4.3.3 System Design

The FSM display and control system is independent of the research cab, so that it may operate in other simulators. Toward this end, the system design is autonomous from the Boeing simulator, except for simulated-aircraft system status data. A direct result of this design philosophy is that the FSM must contain all the functions and capabilities for handling crew alerting; including alert categorization, prioritization, and inhibition schemes, algorithms for handling heuristic systems data, checklist and procedural schemes, status display, and a variety of system control paradigms.

Figure 4.3.3-1 shows a functional diagram of the FSM system. On the far right of the figure are the system-pilot interfaces, the display-control devices. On the far left the airplane host simulator function is shown. To the right of the host simulator is the large monitor and control unit labeled the FSM Emulator. The monitor and control unit is the basic FSM unit. Between the monitor and the system-pilot interface devices are control modules which execute the commands of the controller and control the display devices. They also modulate the pilot control actions affecting the monitor.

4.4 DEMONSTRATION PROCEDURES

As mentioned in Section 4.2, two demonstrations were conducted during Phase I. The procedures were the same in both demonstrations and are described in Paragraph 4.4.1.

4.4.1 FSM Study Team Demonstration

The system was demonstrated with a static airplane simulator using the test scenario for Differential Lift. The sequence of system operation was controlled by microprocessors which permitted test conductor interaction with the alert display and the procedures and status displays. The Basic FSM concept was demonstrated. The test conductor performed the demonstrations, allowing the test subjects to observe and critique the concepts.

The "LEFT ENGINE ANTI-ICE" alert (shown in Figure 4.4.1-1) was presented first. The test conductor pressed the appropriate line select key, which called up a note on the procedures display stating that there was no procedure for the alert. The test conductor then selected STATUS on the alert display, which caused the anti-ice system diagram to appear, as shown in Figure 4.4.1-2. Subsequent selections of the STATUS key called up the operational information shown in Figures 4.4.1-3 and 4.4.1-4. Then, following a simulated scenario of flying in icing conditions, a new alert was generated and presented on the alert display: "L ENGINE VIBRATION". The

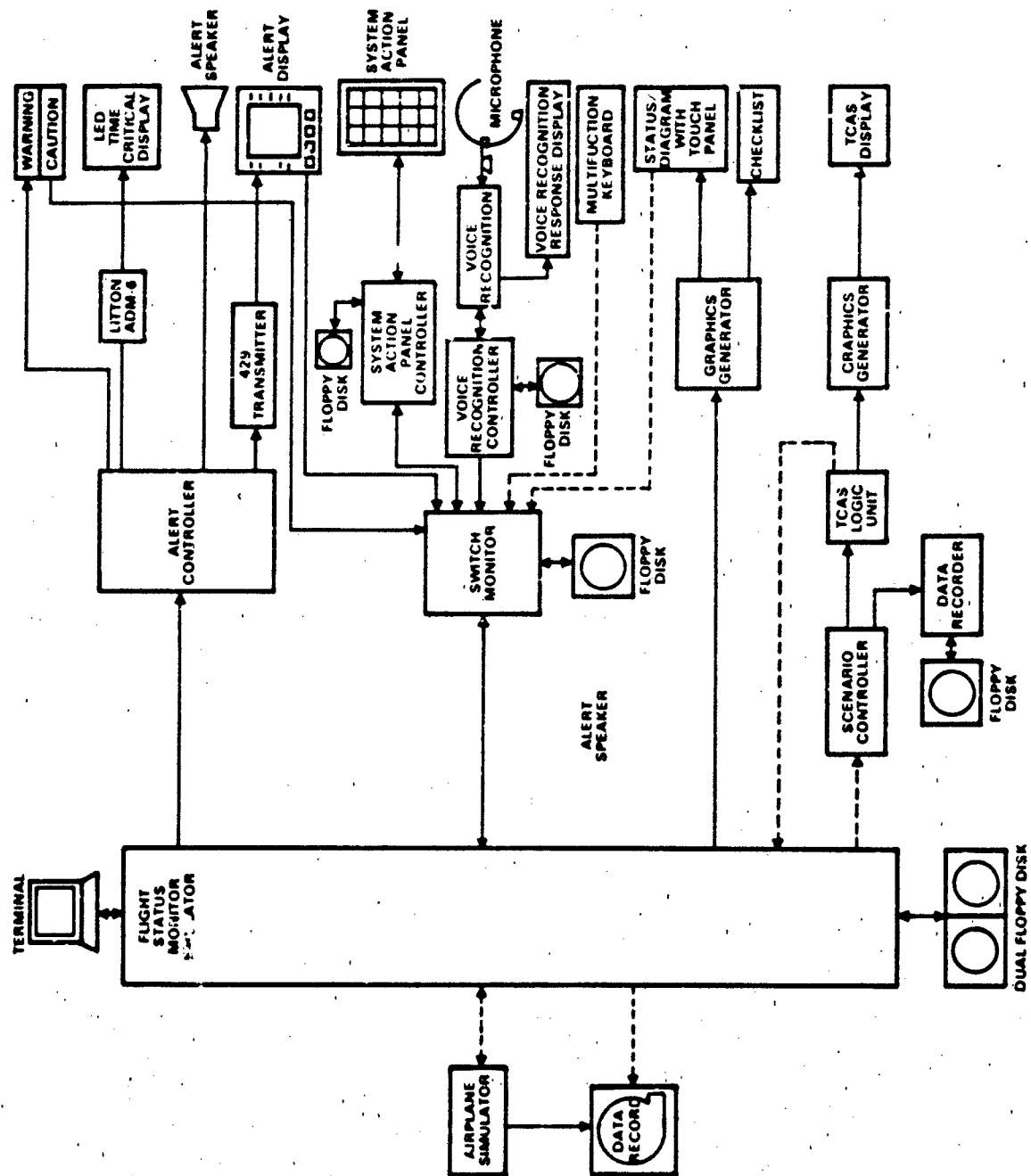


Figure 4.3.3-1 Functional Diagram of the FSM System

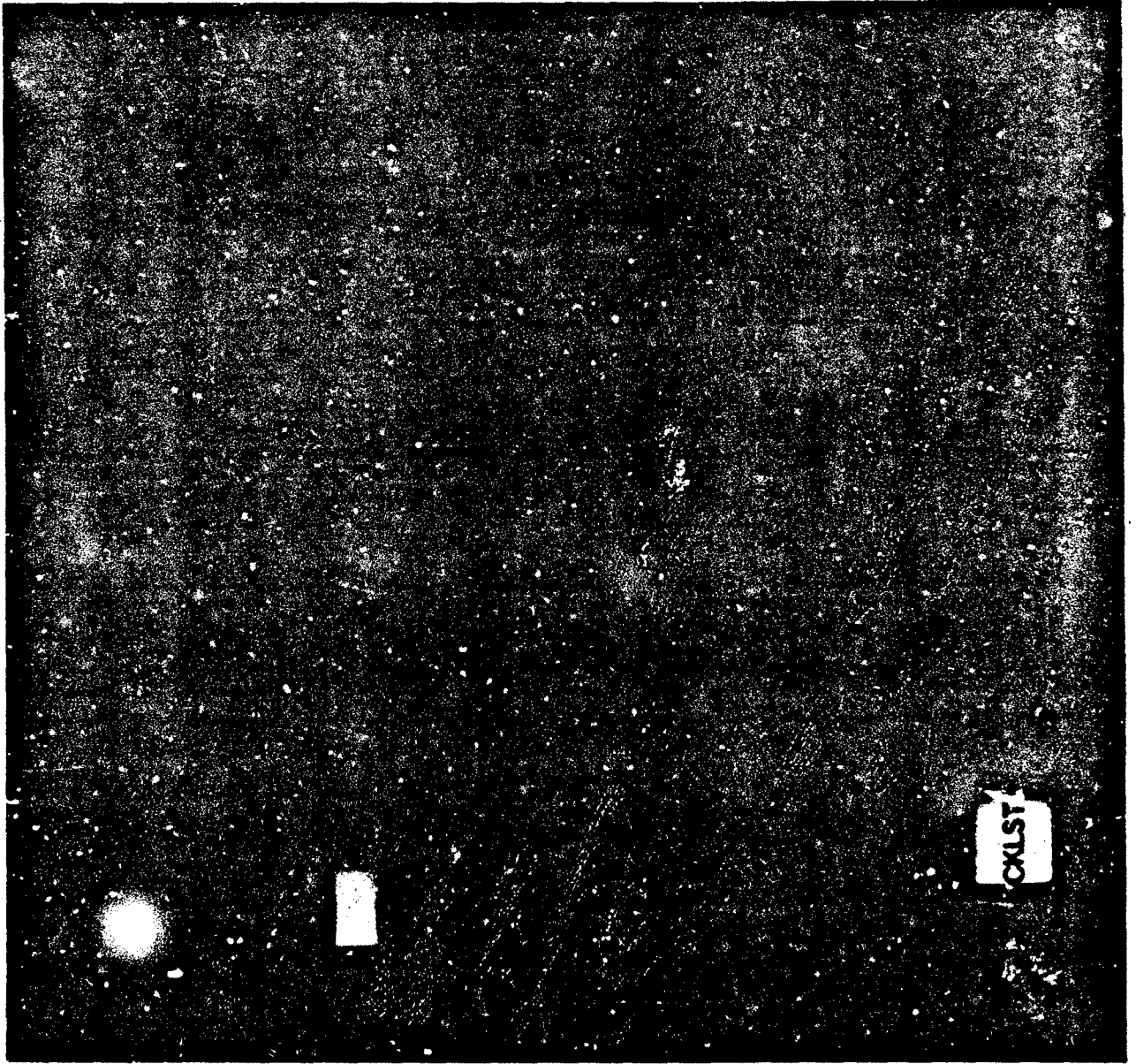


Figure 4.4.1-1 Left Engine Anti-Ice Alert

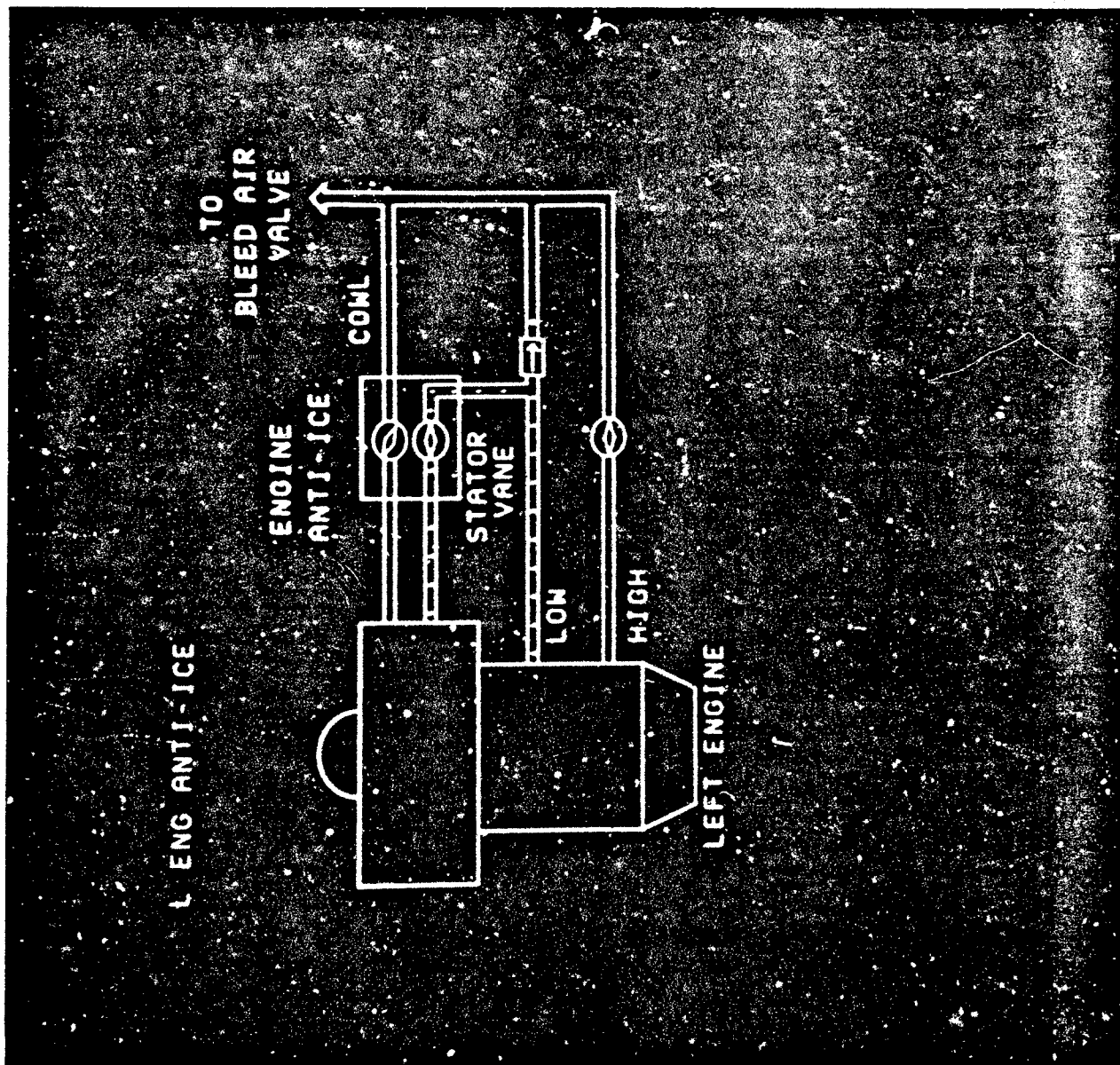


Figure 4.4.1-2 Engine Anti-Ice System Diagram

L ENG ANTI-ICE

THE COOL ANTI-ICE VALVE HAS FAILED.
NO ENGINE ANTI-ICING IS BEING
PROVIDED

LEAVE ANTI-ICE SWITCH ON TO PROVIDE
CONTINUOUS ENGINE IGNITION

AVOID ICING CONDITIONS

Figure 4.4.1-3. Engine Anti-Ice Operational Information

L ENG ANTI-ICE

ICING CONDITIONS EXIST. TOTAL AIR
TEMPERATURE IS BELOW 10 DEG. C.

ICING CAN OCCUR WHEN:
VISIBLE MOISTURE IN ANY FORM IS
PRESENT SUCH AS FOG WITH VISIBILITY
LESS THAN ONE MILE, RAIN, SNOW,
SLEET, ICE CRYSTALS, ETC.

ICE BUILDUP MAY RESULT IN SEVERE
ENGINE DAMAGE AND/OR FLAMEOUT

ERRATIC EPR INDICATIONS OR ABNORMAL
EPR RELATIVE TO NI MAY BE AN
INDICATION OF ENGINE ICING

Figure 4.4.1-4 Engine Anti-Ice Operational Information

test conductor pushed the line select and checklist keys, and the alert procedures were presented on the procedures display (as shown in Figure 4.4.1-5). The test conductor read the displayed information and accomplished the engine shutdown procedure using the system action panel. As each step was accomplished, the action item on the procedures list would change from white to green and a cursor would drop down to the next procedural item. When the checklist was completed, the display was cleared.

Then the test conductor, who was demonstrating the display of a preliminary landing checklist, was given an alert that his Left Leading Edge Slats did not deploy, "LE SLATS ASYM". Upon pressing the line select key and selecting CHECKLIST, the procedure for the alert came up as shown in Figure 4.4.1-6. Using the system action panel (Figure 4.4.1-7) the test conductor accomplished the checklist.

After the checklist had been completed, the test conductor selected STATUS and the aircraft status came up on the status display (see Figure 4.4.1-8). Then, because of loss of airspeed, a warning-level alert was presented on the alert display, "WINGS ASYMMETRY". The test conductor selected the alert and selected CHECKLIST, see Figure 4.4.1-9). The test conductor checked his airspeed and, using the system action panel (Figure 4.4.1-10) pushed the "DONE" button to indicate completion of the procedural step.

Although not dynamically demonstrated, the scenario would have continued with a further loss of airspeed causing a time-critical alert on the glareshield-mounted time-critical display:

"STALL"

"ADD POWER"

The scenario would have ended with the pilot responding to the alert by adding power.

Throughout the demonstration, the study team members and the contract monitor commented on specific FSM design features. A summary of these comments are contained in Section 4.7.1.

L ENG VIBRATION

ABNORMAL INDICATIONS EXIST. SAFE
FLIGHT CAN BE CONTINUED. EXECUTE
ENGINE FAILURE PROCEDURES.

THROTTLE.....CLOSE
WHEN IDLE - FUEL CONTROL SWITCH, CUTOFF
OPERATIVE ENG START SELECTOR.....FLT
APU < 3000 FT MAX >.....START
LEFT DEMAND HYD PUMP SELECTOR.....ON-
PACK CONTROL SELECTOR LEFT SIDE.....OFF
LEFT AND RIGHT ISOLATION VALVES.....OPEN
FUEL BALANCE.....CHECK

Figure 4.4.1-5 Left Engine Vibration Alert Procedures

LE SLATS ASYM

> CHECK THE LE ALTN FLAP LIGHT OUT. CHECK
GND PROX FLAP OVRD SWITCH.....OVRD
ALTERNATE FLAPS SELECTOR.....FLAPS 5
TE ALTERNATE FLAP SWITCH.....ON
SET BUG TOXXX KTS
ALTN-FLAP SEL. AND FLAP LEVER-FLAPS 20

Figure 4.4.1-6 Leading Edge Slats Asymmetry Alert Procedures



Figure 4.4.1-7 System Action Panel

LE SLATS ASYMMETRY

LEADING EDGE
SLATS ARE NOT
EXTENDED

MAX SPEED 220
MIN SPEED 155

LEFT WING
WILL STALL
AT 155 KTS

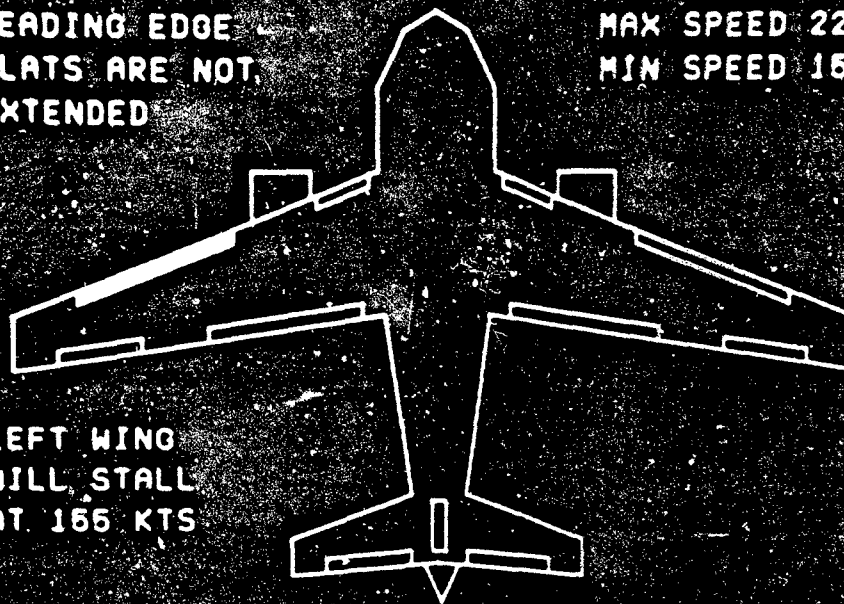


Figure 4.4.1-8 Aircraft Status Display

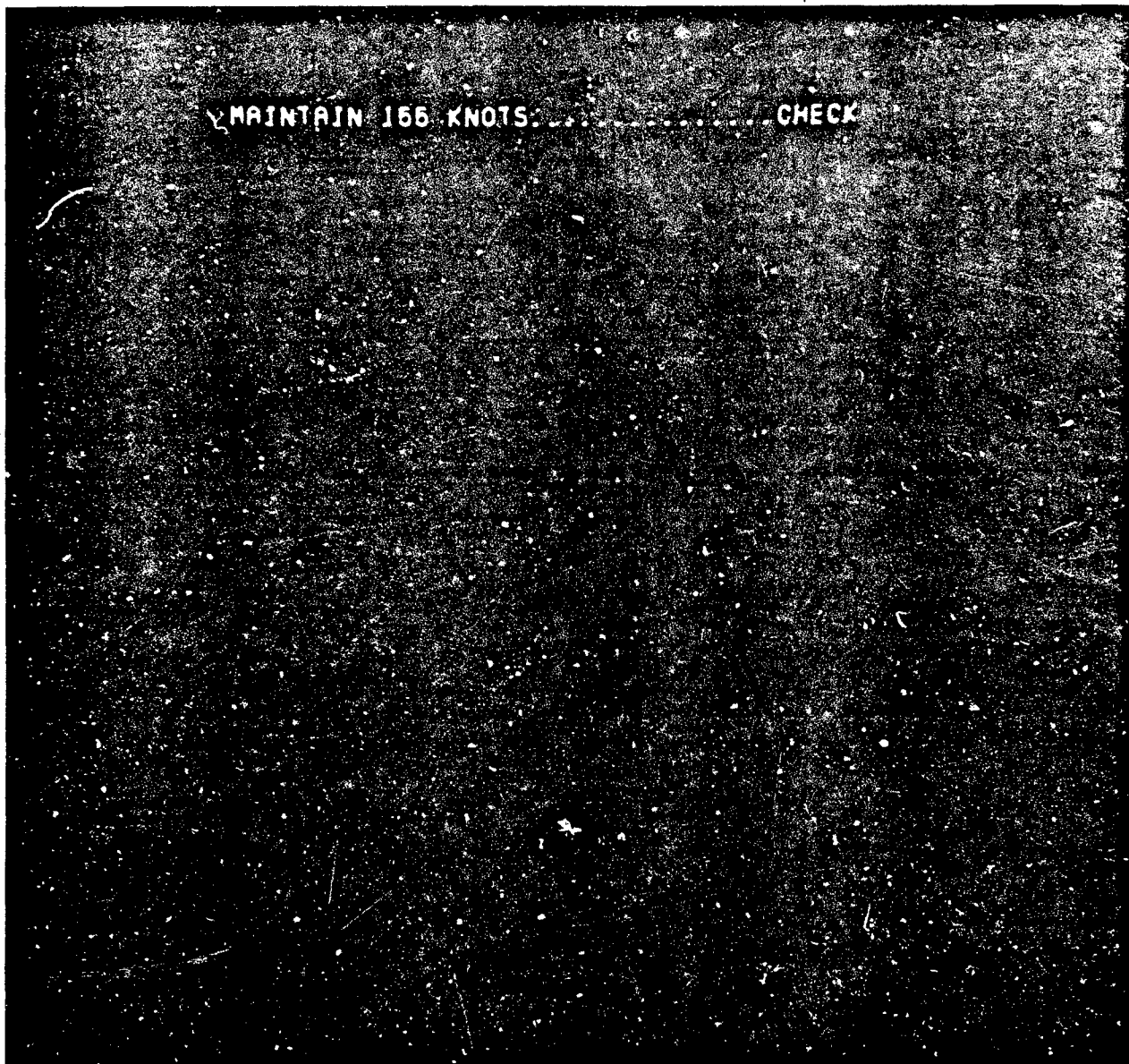


Figure 4.4.1-9 Wings Asymmetry Alert Procedures

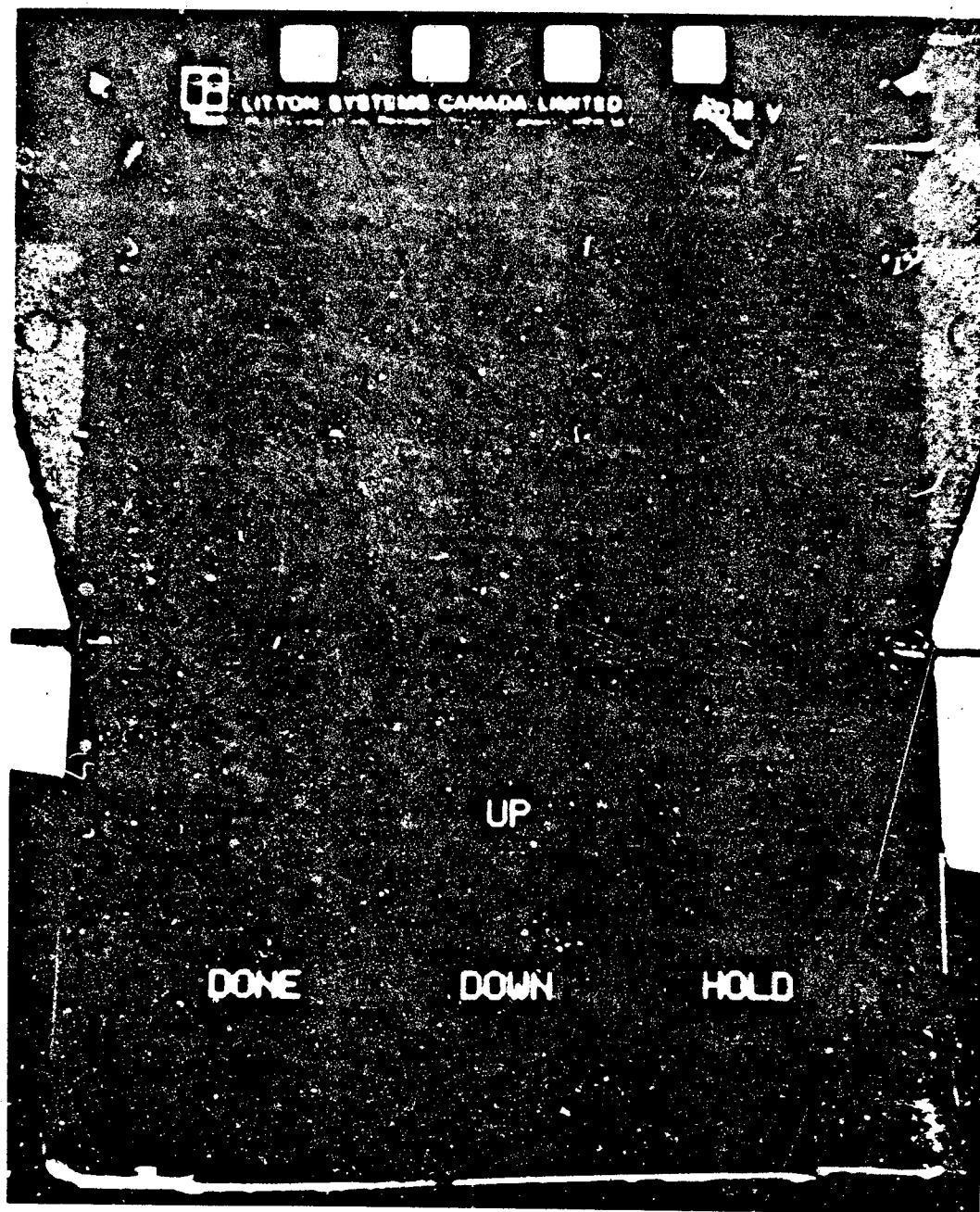


Figure 4.4.1-10 System Action Panel

4.4.2 Pilot Demonstration

On April 13, 1984, six pilots participated in a demonstration of the Basic and the Basic With Automatic Display concepts in the Boeing simulator. All of the pilots were qualified in at least three aircraft and had between 4,500 and 14,000 pilot hours with an average of 8,333 hours.

Before the demonstrations, the pilots were briefed on the objectives and functions of the FSM and on the candidate concepts. The concepts were described in detail, and crew interaction with the system was explained. Questions and comments were solicited from the pilots during the briefing. Following the briefing the pilots were shown the research cab and were instructed as to how the demonstration would be conducted. They were informed that the session was being tape recorded and were asked to speak up, as the noise level in the cab would be high. They were asked to stop the demonstration at any time to repeat or discuss any feature of the system. The test conductor solicited questions and comments. The scenario and FSM concepts demonstrated were the same as those described for the first demonstration in Paragraph 4.4.1. Again, the test conductor performed the demonstrations, allowing the pilots to observe and critique the concepts.

Once initiated, the operation of the FSM was paced by controlled inputs from the test conductor (who narrated the scenario). As questions came up or a discussion broke out, the test conductor would delay the next control input to permit full discussion. The objective was to get the pilots' opinions on the candidate concepts.

Following the demonstration, a transcript of the tape was made and analyzed. A summary of these comments is contained in the next section.

4.5 DEMONSTRATION RESULTS

The results of the study team and pilot demonstrations are summarized separately below.

4.5.1 Study Team Demonstration Results

Review of the demonstration concepts and scenario led to a consensus for the following refinements in preliminary concepts:

- o Increase size of characters on checklist/procedures display.
- o Color code failed/degraded components on schematic diagrams with the same color as the urgency level of the alert.
- o Information on the procedures display should be directive and positive. For example, it is better to use:
 "Maintain 155 KTS airspeed", instead of
 "Check airspeed ----- check"
- o On aircraft-level schematics, only color-code failed systems/components due to the small size of the display.

4.5.2 Pilot Demonstration Results

The following comments were derived from the analysis of the pilot demonstration transcript. The comments listed are those made by one or more of the pilots. In general, most of the comments were derived on the content and format of the procedures and status displays and on the level of automation; the following comments are reported in that respective order. The pilot's suggestions will be considered along with the literature review results and questionnaire feedback, during the refinement of Phase I concepts.

4.5.2.1 Procedures Display Comments

- o Completed action items should remain displayed until the entire procedure is completed.

- o Completion of the procedure should be acknowledged by the crew before the action items are cleared from the display.
- o Procedural action items presented "up front" was preferred. It would also make one less book to carry around.
- o Although displayed procedures were favored, electronic checklists could pose a problem when airworthiness directives require a change in procedures, because of the complexity and security of software changes. Current paper checklists are easily altered.
- o A completely modifiable checklist, needed to avoid the problem of changing a checklist and conforming to a software verification requirement, would be a formidable task.

4.5.2.2 Status Display Comments

- o Pilots stated that the display of aircraft level status did not extend their knowledge of the aircraft's condition. For example, "If a pilot needs a picture to tell him that the Left Leading Edge Slat is not extended, he has got a problem."
- o There is no need to display systems diagrams with failed components if the flight crew cannot repair them.
- o Aircraft level status displays should show maximum and minimum speed limits.
- o Studying the status display will cause the pilots to keep their heads down.
- o Status display would not help the pilot respond to alerting situations.
- o The use of status or graphic displays, like those demonstrated, have never been as useful as envisioned. Pilots stated that in general, they need to be improved and that more format development was needed.

4.5.2.3 "Level of Automation" Comments

- o For warning level alerts, the procedures and status displays should come up automatically.
- o In general, the pilots favored automatically executed checklists, but they wanted the capability to select the AUTOMATIC mode.
- o The pilot must have the capability to halt the automatic completion of a checklist.
- o Regardless of the design, the pilot must always retain control over the aircraft.
- o Automatic checklist might be beneficial when the flight envelope is reduced through some failure in the flight control augmentation system.
- o Allow the pilot to control the length of time between the execution of action items on automatically completed checklists.
- o With a turbine shaft shear there could be as little as 2/5 of a second to shut down an engine. In such a case, manual shutdown is too slow, and, without major structural encasement, automatic shutdown is required.

4.5.2.4 Voice Message Comments

- o A smart system should include voice messages as a redundant mechanism for providing crew guidance and feedback in responding to alerting situations.
- o A voice message such as "NOSE DOWN" or "ADD POWER" might help the crew in situations like those encountered in the Chicago accident.

5.0 ACCOMPLISHMENTS AND RECOMMENDED FUTURE ACTIVITIES

5.1 SUMMARY OF ACCOMPLISHMENTS

The following major tasks were accomplished during Phase I:

1. FSM System Requirements - Based on the results of Phase IV, an approach was taken to expand the alerting system to function as an FSM. FSM functional requirements were developed on the assumption that by providing flight crews with procedural guidance information and feedback crew performance in non-normal situations could be improved.
2. FSM Control and Display Requirements - Candidate control and display suites were identified to satisfy the FSM functional requirements. Information requirements can be accommodated by one or more color displays. In our present configuration, two color displays are used; one provides step-by-step procedures for resolving aircraft alerting situations and one provides aircraft and system status. To satisfy the control requirements for interacting with the FSM and accomplishing the procedural action items, several candidate concepts were identified including: voice control, touch-interactive displays, multifunction keyboard, and automatic reconfiguration.
3. FSM Implementation Issues - For each of the candidate control and display suites identified above, implementation issues were addressed. Basically, these issues focused on identifying all of the design questions relating to the content, format and crew interaction mechanisms for implementing the candidate FSM concepts.
4. Candidate System Concepts - System concepts, differing in their level of automation, were developed for satisfying the FSM requirements. These concepts ranged from manual control through system aided control and finally to automatic system reconfiguration. A total of six concepts were developed: Basic (manual control), Basic with Automatic Display, Touch-Interactive, Voice-Interactive, Multifunction Keyboard with scratchpad, and Automatic reconfiguration.
5. Demonstration Scenarios - Scenarios were developed to provide a mechanism for demonstrating/evaluating the candidate system concepts. The story lines for the scenarios were abstracted from accidents and incidents that were reviewed as part of the Phase IV effort. Three scenarios were developed: (1) Differential Lift, (2) Takeoff Abort, and (3) Navigation Error.

6. FSM Concept Evaluation - Two FSM concept demonstrations/evaluations were conducted. The study team members and the FAA contract monitor participated in the first demonstration, and six Boeing pilots participated in the second demonstration. The demonstrations were conducted in Boeing's flight station research and development laboratory. The demonstration consisted of a test conductor going through the simulated Differential Lift scenario with the Basic (manual control) concept implemented in the scenario. Whereas only the Basic concept was implemented, all other control concepts were reviewed. During the demonstrations, participants comments and opinions were solicited to provide information for refining the candidate concepts.
7. Candidate Concept Refinement - In addition to the system demonstrations, a literature review and a questionnaire were developed to provide data for refining the candidate concepts. The literature review focused on resolving the candidate concept implementation issues. The questionnaire was directed at evaluating the relative effectiveness of the candidate concepts and evaluating specific design features of each concept. The questionnaire will be administered early in Phase II to provide data for finalizing the FSM candidate concepts for further test and evaluation.

5.2 RECOMMENDED FUTURE ACTIVITIES

5.2.1 Continuation of Phase I

In the course of the Phase I effort it was decided that additional data will be required to supplement the information acquired from the literature review and system demonstrations to refine and reduce the number of candidate concepts for the Phase II effort. To help acquire this data, a questionnaire was developed which will be administered early in Phase II. In addition, one or more system demonstrations will be conducted.

5.2.2 Phase II Activities

The objective of Phase II is to implement selected FSM functional concepts in special test hardware and evaluate them in a simulated operational environment. The major activities to be accomplished in Phase II are summarized below.

1. Develop FSM Simulation Specifications - The objective of this task shall be to incorporate the changes in FSM functional concepts. First, the system specification will be modified to incorporate the functional changes derived from the Phase I demonstrations. Appropriate changes recommended by the observers of the concept demonstration will be implemented.

Secondly, and more significantly, the concept system to be exercised and evaluated in Phase II will be a more complete system. More alerts for a broader range of alerting functions will be implemented. Many functions previously handled by the host computer for the Phase I demonstration will be designed into the FSM real-time test configuration.

In addition, the test plans and the simulation scenarios will be altered to meet the requirements for the Phase II evaluation. Scenarios and equipment will be changed as necessary to permit accumulation of pilot performance and preference data.

2. Develop Simulator Demonstration Systems - Suitable hardware shall be assembled for the Phase II evaluation in an operational simulator. Hardware subsystems will be configured and reprogrammed to perform functions which were either not demonstrated in Phase I or were accomplished by the host computer. Necessary interfaces will be modified to link the system to the flight simulator. Wherever possible, the special test equipment will be of a quality capable of flight evaluation.

Prior to installation in the simulator, the system components shall be bench tested to insure proper operation. This task will include testing of subcomponents of the special test equipment as they are reconfigured. Additionally, as more subassemblies and capabilities are added to the test system, operational tests will

be performed to ensure operability and compatibility. When available, the complete test assembly will be bench tested as completely as possible, before installation in the simulator.

The test equipment shall be installed and its operation in the flight simulator will be verified. Because not all functional tests can be accomplished on the bench, extensive testing may be required when the test equipment is installed in the simulator. This testing will include subassembly testing, such as the aural signal generator, the displays, and the data collection/input devices.

The complete system will be tested. The simulator elements such as the cockpit displays and controls and the simulator handling qualities will be checked out. Finally, the concept system will be pre-tested in test scenarios under test conditions. Prior to conducting the actual test and evaluation, a limited number of sample tests will be conducted to assess the reliability of the system and to solidify test procedures and the test schedule. This task will involve approximately 40 hours of simulator time.

3. Perform Demonstration/Test and Evaluation - Test shall be performed using suitable subject pilots. This task will involve approximately 60 hours of testing in the flight simulator. The tests will be conducted in accordance with the detailed test plan. The test subjects will be selected according to the test plan, and shall be line qualified pilots. Both contractor and subcontractor personnel shall provide representation at the tests to assure the tests are conducted according to plan, to assist in the conduct of the tests, and to facilitate the data reduction and analysis.

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APPENDIX A

DETAILS OF DISPLAY-CONTROL SYSTEM OPERATION (FROM LITERATURE REVIEW)

Gartner and Holzhausen (1979), page 13

Checklist access and completion steps:

1. The main dispatcher (menu) is displayed. The operator has access to any mode from this keypad - he chooses "CHK" for "checklist" by touching the "CHK" switch.
2. The Checklist subdispatcher (sub-menu) appears and the main dispatcher disappears. The operator identifies the desired procedure by touching the associated switch (such as "PFL" for "pre-flight" checklist).
3. The first page of the desired checklist comes up. The operator indicates a completed item by touching the switch next to that item, thus each item of the procedure has a switch associated with it.
4. After completion of a page, the next page automatically appears on the display.

The authors did not discuss what transpires after the procedure has been completed, but they did mention that the user can return to the main dispatcher at anytime during the procedure by touching the "HOM" key, which remains on the display throughout the exercise.

Streeter, Weber, and Opittek (1973), page 13

Manual and automatic progression through data levels:

The pilot could call up a schematic diagram or checklist procedure manually in one of two ways; step-by-step through all data levels, or by direct access to the desired level. Each line of data would have a number associated with it, left of the line item (see Figure A-1). The operator would touch the line number to see more detailed information pertaining to that specific line, thus moving through all data levels. Otherwise, the controls at the bottom of the display would be used for direct access to

| | | |
|----|--------------|------------|
| 1 | LDG GEAR | ✓ UP |
| 2 | WING SWEEP | ✓ 35 AUTO |
| 3 | SL/FL/SPD BR | ✓ 10/35/UP |
| 4 | FLT CNTLS | ✓ SAS |
| 5 | FUEL | ✓ 9000 |
| 6 | ELECT | ✓ NORM |
| 7 | HYD | → 3000 |
| 8 | NAV/COMM | ✓ NORM |
| 9 | FLT INST | ✓ NORM |
| 10 | CAB ALT | ✓ 8000 |
| 11 | ARM/AWCS | ✓ OFF/RDR |
| 12 | CHECKLISTS | -- |

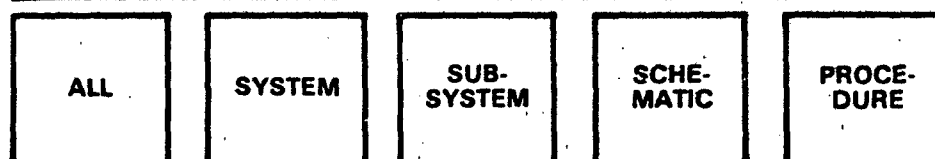


Figure A-1 Checklist Procedure with Associated Line Numbers (Streeter, et al, 1973)

other levels, specifically to a schematic or checklist procedure. Automatic access to checklist procedures would be provided for warning-level conditions. When a warning was sensed, the appropriate procedure would be displayed immediately. In the event that more than one warning-level alert had occurred, the highest priority procedure (as determined by the system logic) would be presented.

A fourth method would be available only for checklist selection. The word "checklist" would appear at the bottom of the status display. Activation of the "checklist" line would cause a checklist index to appear. The operator could then choose the desired checklist procedure.

Sexton (1983), page 15

Normal and abnormal checklist operations:

Checklist operations were described for both normal and abnormal situations. The process is essentially the same, except for the call-up of procedures. In both cases, checklists are presented at the top of the display and schematic diagrams at the bottom (see Figure A-2). Dedicated touch panel controls for checklists included:

- Abnormal Checklist (ABN)
- Emergency Checklist (EMER)
- Normal Checklist (NORM)
- Index (INDX)
- Page Advance (ADV)
- Page Reverse (REV)
- Clear Checklist (CLR)
- Checklist Incomplete (CHECKLIST INCOMP)

The operation of a "normal" procedure will be described first, followed by the operation of an "abnormal" procedure.

NORMAL PROCEDURE CHECKLIST OPERATION

- o Initial power application causes the first sequenced checklist to appear.

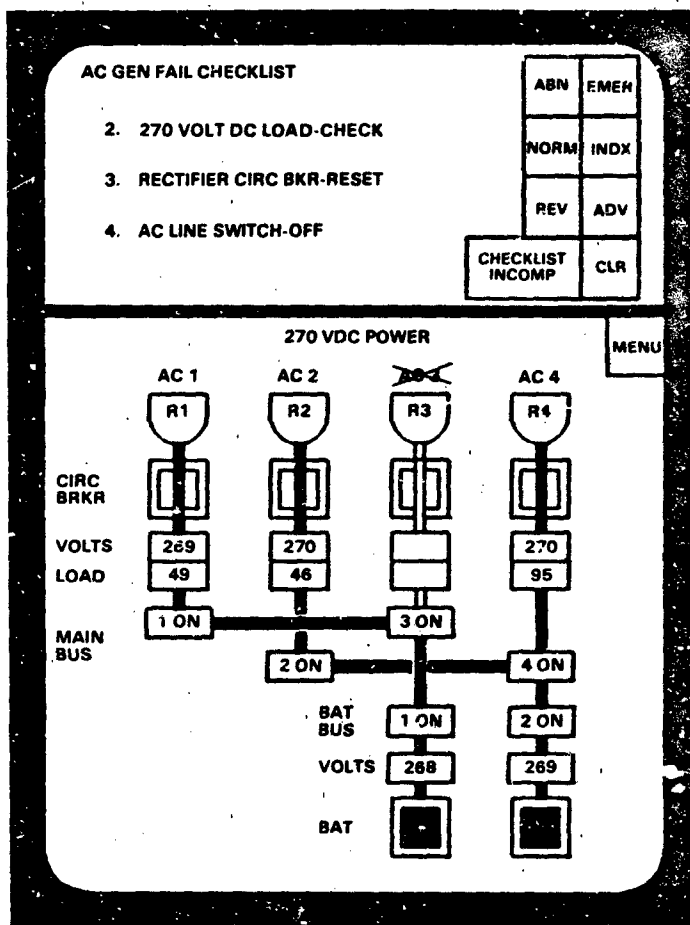


Figure A-2 Sample Checklist and Schematic Diagram (Sexton, 1983)

- o Each item is checked off by pressing the line item (anywhere on the line).
- o After an item has been checked off, it scrolls off the top of the display and the next item scrolls onto the bottom of the checklist area.
- o When an item reaches the top of the display, the associated schematic diagram appears below the checklist.
- o Items may be skipped by pressing a line other than the one at the top. Thus, all lines above the chosen item are skipped and a message appears beneath the touch panel switches which reads "Checklist Incomplete". The chosen item moves to the top and the appropriate schematic appears.
- o To recall a skipped item, the operator would press the "Checklist Incomplete" message, and the first skipped item would appear at the top of the display. All other items would fall into place below the first skipped item. (The author did not mention whether or not a schematic diagram would appear at this time.)
- o To recall other skipped items, the operator would again touch "Checklist Incomplete". The next skipped item would then replace the previously chosen skipped item at the top of the display.
- o This sequence would continue until the last skipped item was chosen, then begin again with the first skipped item.
- o When an item is checked off after having been called up through the "incomplete checklist" mode, the system reverts to normal operation.
- o A "Clear Checklist" (CLR) switch is provided on the touch panel. When pressed, it clears all remaining items from the display and the checklist sequence continues.
- o As each checklist is completed, the next procedure in the sequence automatically appears on the display. To display an out-of-sequence procedure, the operator would press the Index (INDX) button to see a list of potential checklists. A checklist would be chosen by pressing the name of the desired procedure.
- o If the operator wants to see the index of abnormal or emergency checklists, the ABN or EMER button must be pressed before touching INDX.

ABNORMAL PROCEDURE CHECKLIST OPERATION

- o When a malfunction occurs which provides an alerting message and has a checklist stored in memory, pressing the appropriate ABN or EMER button automatically displays the correct checklist and schematic diagram.
- o Once a checklist has been begun, the operator's position will be maintained if the checklist is interrupted for any reason. Thus, if the operator is performing a normal procedure and a malfunction occurs, the ABN or EMER switch would be pressed to call up the malfunction-correction procedure. After completion of said procedure, the operator could press the NORM switch and return to the most previous position in the normal checklist.
- o The Reverse (REV) and Advance (ADV) switches move displayed items up or down within a checklist or index, three items at one time. When at the end of the list, one button push moves each item one at a time. These switches access procedures in sequence; thus, after the operator reaches the end of one checklist, the next checklist can be accessed by pressing ADV.
- o To activate a checklist using voice commands, the operator would press the voice command switch (located on the joystick) and say the name of the desired procedure. The requested checklist would then appear on the display, and operate as described above.

A310 Electronic Centralized Aircraft Monitor (ECAM), page 17

During normal operation, the left CRT shows a memo list which reminds the crew of systems or functions that are in use, enabling significant items to be checked without the need to scan the overhead panels. Flight phase information is presented automatically. System information is presented in synoptic format whenever possible. Figure A-3 shows the normal displays for the ENGINE START phase of flight.

When a failure is detected by the flight warning computer, the left display provides an explicit description of the failure, and it is color coded in either red or amber, according to the fault level. The right display automatically presents the proper system synoptic. An example is presented in Figure A-4.

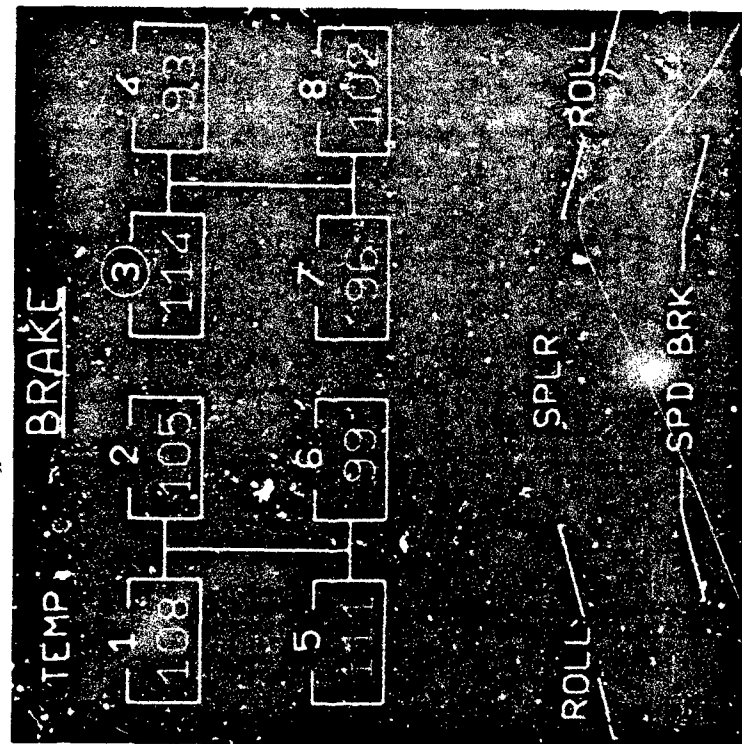


Figure A-3 ECAM Normal Displays for Engine Start

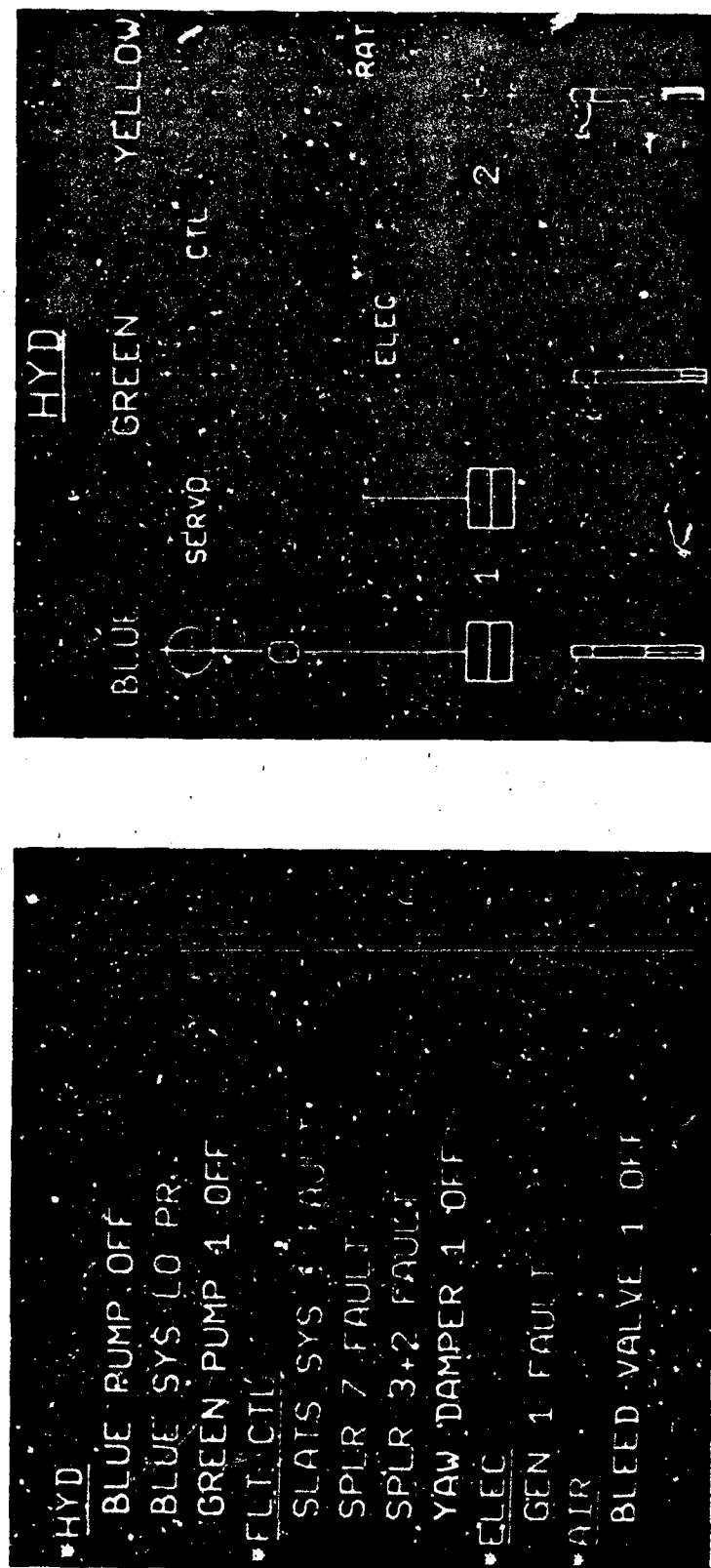


Figure A-4 ECAM Hydraulic Failure Displays

The generating failure (system-level fault to which crew is alerted) is presented alone on the first page of the left display. Any consequential failures (faults which come about as a result of the generating or primary failure) are presented on the second page and will only appear if resolution of the generating failure is not successful. Transition from the first to the second page is made by selecting the CLEAR key. If simultaneous failures occur, they are presented according to a defined priority order.

As often as possible, corrective actions are presented adjacent to the failure description. Crew actions appear in cyan. Once corrective actions are performed and sensed by the flight warning system the cyan instructions turn to white. Items performed automatically (by the system) and requiring no crew action are displayed in white. If an action eliminates the problem, the line is deleted after the action item has been completed. The action code is given in checklist style and only one item is presented on each line. Each time a failure results in a flight envelope limitation, the limitation is indicated in cyan adjacent to the failure description.

Upon selection of the CLEAR key, a status page appears which shows an operational summary of the aircraft condition, the status of failures which affect the flight operations, and clean-up procedures. The status page may be recalled anytime during flight by selecting the STATUS key.

After all action items pertaining to the generating failure have been completed, the crew member selects the CLEAR key. This will bring up any consequential failures. After these actions have been completed, the selection of the CLEAR key will bring up the status page, and selecting the CLEAR key again will bring up the memo page.

The wording and abbreviations on the left display are consistent with the overhead panel. Lines which begin with conditional statements are shown in cyan and begin with a decimal point. Status information appears

in green if the system is operational, and in amber or red (according to fault level) if the system is non-operational. Memo items are presented in green (see Figure A-5).

There are fourteen synoptic displays on the right CRT. These use simplified schematics to show the arrangement of system components. Color coding is used to indicate the status of the system. Quantitative information is presented by either numeric displays or analog scales. Abbreviations are used to identify components. These displays will appear automatically when an associated failure occurs, and may be called up manually by selecting the appropriate key on the display control panel.

Gallon and Currin (1984), page 17

When a failure occurs, the right CRT automatically changes. The failure is listed in the alert list, the memo display changes to show procedures and aircraft limitations, and the flight phase display changes to the applicable system schematic.

The alert list contains fourteen lines. Alerts are prioritized according to fault level and color coded. A cursor is used to identify which procedures and schematics are being displayed. As the actions are completed and the alert conditions no longer exist, the message is removed from the list.

When an alert occurs, both the procedure and limitations affecting aircraft operation are presented automatically. The procedure includes crew actions required, and actions completed by the system. The procedures are divided into primary actions (which are actions affecting the safe operation of the aircraft) and secondary actions (which are cleanup procedures to protect the equipment). For a "Level 3" (e.g., warning-level) alert the primary procedures as well as the operational limitations for the current flight phase are presented. For a "Level 2" (e.g., caution-level) alert the operational limitations affecting the current flight phase are

STS 20 LARD 3 INOP
 HYD BLUE SYS INOP
 SEN 1 INOP
 SPLR PARTIALLY INOP
 SLATS SLOW

CAB PRESS AIR COND
 CAB ALT TEMP
 256 20
 V/S 11.11
 1.0
 ENGINE
 N1 VIB N2 VIB
 0.000.0 0.000.0
 OIL TEMP
 148 148
 FWD FWD MID AFT
 18 18 18 22
 BULK 18

Figure A-5 ECAM Status Display Following Hydraulic Failure

presented. For either alert the secondary procedures are presented below the primary procedure or on a second page (see Figure A-6).

All action items must be addressed by the pilot. Some items (such as SET actions) can be sensed by the system, and change color after completion. Other (such as CHECK items) cannot be sensed, and remain the same color throughout procedure completion. An asterisk precedes each item of this type.

After completion of all procedures, the status page is presented automatically (see Figure A-7). The status display contains all current and potential aircraft limitations, outstanding procedures for later flight phases, and operationally significant modifications of aircraft systems.

When an abnormal procedure is displayed, the flight phase display automatically changes to show the associated system schematic. This schematic duplicates the overhead panel as much as possible and is color coded according to fault level. The displays are interactive and reflect the actual system configuration to the extent practical. This display remains until the FLIGHT PHASE key is selected. These displays maybe selected manually by pressing the appropriate key on the MFD control panel.

In summary, after an alert, the pilot is directed to review the procedure, the backup procedure, and the aircraft status information pertaining to the current aircraft status. The pilot has the capability to page through the information pages and to recall information. The pilot may continue to page through the abnormal procedure loop, and when all items have been satisfactorily addressed, he leaves the procedure by pressing the FLIGHT PHASE key. At any time, the pilot may select the STATUS key and the status page will return. If he selects the FLIGHT PHASE key without completing the abnormal procedure, the memo list will indicate status. Upon selecting the STATUS key, the status page will contain the outstanding procedural items.

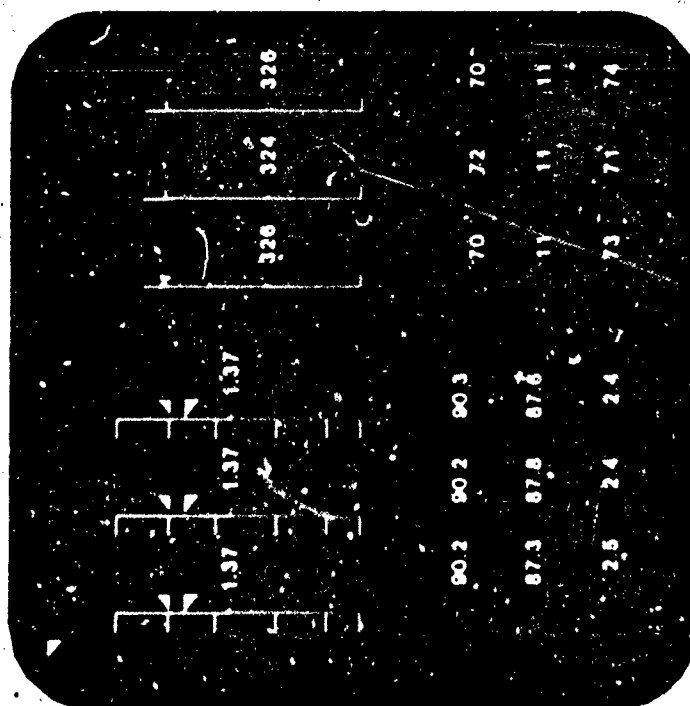
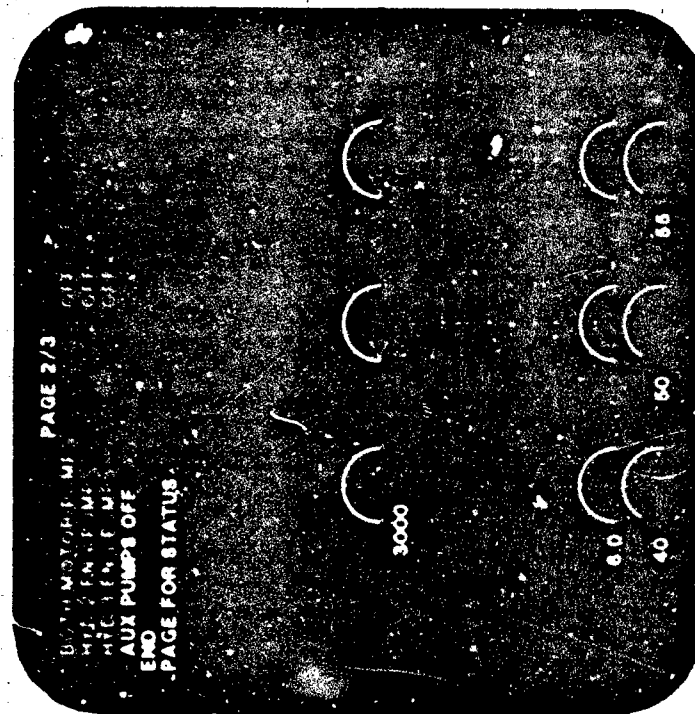


Figure A-6 MFD Secondary Procedure and Display (Gallon and Currin, 1984)

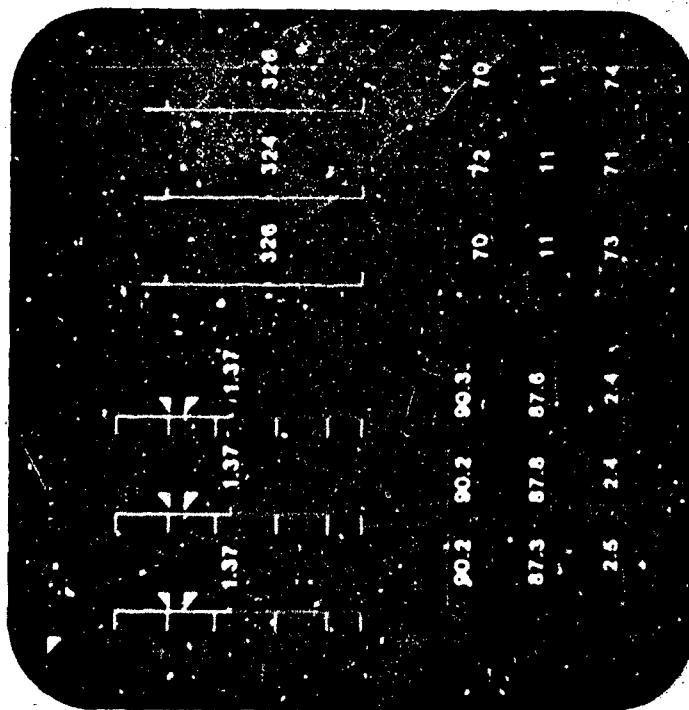


Figure A-7 MFD Status Page (Gallon and Currin, 1984)

Pfauth and Priest (1981), page 21

Touch screen design considerations:

1. Dialogue development/Menu-hierarchy
2. Feedback (auditory, visual or tactile?)
3. Size of target (recommend 22 mm)
4. Shape and color coding
5. Distance between controls (depends on application)
6. Activation force required
7. Time delay between touches
8. Mode
9. Resolution required for task
10. Potential parallax problems
11. Display size
12. Reliability

In addition, the following work-place considerations exist: temperature and humidity; electromagnetic field interference; dirt and grease; reach distance and fatigue.

APPENDIX B

PILOT QUESTIONNAIRE

PILOT QUESTIONNAIRE AND INSTRUCTIONS

Pilot Questionnaire

Note: This study is designed to assess the advantages and disadvantages of the Flight Status Monitor concept for possible use in commercial aviation. All information you give on this form will be kept confidential and will be summarized statistically with the data from other questionnaires.

Leave Blank
Subj. assigned code: _____

Exp. No.: _____
BOT: _____
EOT: _____
Vis. Tests: _____
Form Compl. _____

(Please Print all answers)

Name: _____

Address: _____

Phone (office pref.) () _____ Birthdate: _____

Do you wear glasses/contacts while flying? yes no (circle)

If you have no military experience skip question 1a. - 1d.

=====

1a. Military Background: Branch _____

b. Did you receive military pilot training? yes no (circle)

c. List aircraft types in which you trained (if applicable - otherwise leave blank)

1st _____ 2nd _____

3rd _____ 4th _____

d. List all aviation-related (specialized) training: _____

(continue on opposite side if necessary)

=====

Please try to be as complete as possible on this question. Include your Civil (noncommercial-private), airline and military flight experience in this table following the sample given. Place a check in the small box for those aircraft for which you hold a "type" rating.

Sample

| Aircraft Type/Model | | Crew Position | | | | |
|-------------------------------------|--|---------------|-----------|------------|-----------------|-------|
| | | Pilot | Copilot | Instrument | Flight Engineer | Other |
| B 707 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | 300 | 2850 | | 1200 | |
| <input checked="" type="checkbox"/> | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | 3/73-5/77 | 4/68-3/73 | 1 | 2/65-4/68 | 1 |

☒ Check here if "type" rated
 Check one for
 c = civil
 a = airline
 m = military
 From/to
 Insert total hrs at top of box

| Aircraft Type/Model | | Crew Position | | | | |
|---------------------|--|---------------|---------|------------|-----------------|-------|
| | | Pilot | Copilot | Instrument | Flight Engineer | Other |
| 1 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 2 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 3 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 4 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 5 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 6 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 7 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |
| 8 | <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; padding: 2px; margin-right: 5px;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">c</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">a</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">m</div> </div> <div style="margin-left: 5px;"> Hrs Date </div> </div> | | | | | |

2.a Total hours flown (approx.) _____ 2b. Years flying since solo: _____
not including Flight Engr: _____

3. Have you had any R&D experience as a member of a development project team
for an advanced flight deck design?

_____ Yes

_____ No

If yes, please describe experience _____

FSM DISPLAY AND CONTROL QUESTIONNAIRE

INSTRUCTIONS

Boeing, Douglas, and Lockheed are conducting a study for the FAA to develop a Flight Status Monitor (FSM). This system will be designed for implementation into future commercial aircraft, for the purpose of providing crew alerting for non-normal situations, guiding the response to these situations, and giving the crew feedback as they respond. The system will be flight phase adaptive and will have alert prioritization and categorization capabilities, as well as the potential for alert inhibition.

The team has constructed several candidate display and control systems. These candidates represent initial attempts to develop FSM concepts. As pilot input is fundamental to the design of such a system, your participation is requested.

Please fill out the following questionnaire as best you can. Notice that after each question, space is provided for an explanation of your response. Please use this space (and the back side of the paper if necessary) to provide a sufficient amount of information, so that we may adequately interpret your answers. A "yes" or "no" response is much more meaningful when clarified than when not.

Thank you for your time and effort.

(Examples and illustrations have been provided where it was felt clarification was necessary. If you have any questions, please contact Don Hanson or George Boucek at (206) 655-8626/2008.

The guidance and feedback functions of the Flight Status Monitor are performed by the procedures and status displays and their associated controls. The following questionnaire will be directed toward these three topics.

I. Procedures Display

The purpose of this display is to provide the flight crew with step-by-step procedural information which will permit them to respond to non-normal situations. This display will have the capability of providing information that is currently presented in the Flight Manual and Operations Manual. The procedures display would also have the capability of presenting checklists for normal operations. The picture presented as Figure B-1 is a possible format for the procedures display. Please answer the following questions concerning the display:

LE SLATS ASYM

CHECK THE ALTN FLAP LIGHT OUT CHECK
AND PROX FLAP OVRD SWITCH

ALTERNATE FLAPS SELECTOR.....FLAPS 5

TE ALTERNATE FLAP SWITCH.....ON

SET BUG TOXXX KTS

ALTN FLAP SEL. AND FLAP LEVER, FLAPS 20

Figure B-1 Sample Procedures Display Format

1. Compared to the operation of using the Quick Reference Handbook and Flight Manual for non-normal procedures, rate the effectiveness of using a procedures display to provide the handbook information.

☐ Current operation much better
☐ Current operation somewhat better
☐ Both about the same
☐ Procedures Display somewhat better
☐ Procedures Display much better

Comments _____

2. Check the situation in which the procedures display should be used.

☐ All non-normal conditions
☐ Warning level alerts only
☐ Warning and caution level alerts
☐ All normal and non-normal procedures
☐ No use at all

3. What type of information should be presented on the procedures display?
(Check all that apply)

☐ Action items necessary to perform a procedure (e.g.
THROTTLES CLOSECLOSE)

☐ Pertinent information (not a specific action item) relevant to the
situation and the conduct of the flight (e.g., WHEN STRUCTURAL
DAMAGE SUSPECTED, AVOID HIGH IAS & ABRUPT MANEUVERING).

☐ An indication that the action item has been completed (e.g.,
change action items, color, or size, or brightness

☐ Other (specify) _____

Comments _____

4. Should the procedures display present procedural information only
(dedicated) or could it be used to display other flight information
(e.g., messages, flight profiles, etc.) when no procedures are present?
(check 1)

☐ Dedicated

☐ Multifunction

Comments _____

5. How many procedural steps (action items) should be presented on the display at one time?

_____ One: current step only

_____ Three: current, past and next steps

_____ All actions for a procedure

_____ Other (please specify) _____

Comments _____

6. Which of the following formats do you prefer for action item presentation?

_____ PUMP 1 ON ----- ON

_____ PUMP 1 ----- ON

_____ TURN PUMP 1 ----- ON

_____ TURN PUMP 1 ON ----- ON

_____ OTHER _____

Comments _____

7. In general when should abbreviations be used in listing the action items?
(Check 1)

☐ Always

☐ Whenever an abbreviation is used on a particular display, it should be used throughout that particular display to be consistent

☐ Whenever an abbreviation is used on one display, it should be used on all displays to be consistent

☐ Only when needed to compress an action item into one line of the display

☐ Never

☐ Other (please specify) _____

Comments _____

8. Referring to the first action item of Figure B-1, "CHECK THE LE ALTN FLAP LIGHT OUT CHECK <". If more than one action item is displayed at one time, which indicator should be provided for the current action item?

☐ Symbol to the left of the action item (">", "**")

☐ Symbol to the right of the action item (">", "**")

☐ Symbol on both sides of the action item (">", "**")

☐ Color code the action item

☐ Brightness code the action item

☐ Flash the action item

☐ A combination of the above. specify _____

☐ No indication is required

☐ Other _____

Comments _____

9.a. How should the crew be provided feedback that an action item has been completed? (Rank the following methods from 1 to 7 with 1 being the most preferred and 7 being the least - mark an "x" beside the ranks for those methods you consider unacceptable)

- ☐ Completed items removed from screen
- ☐ Completed item different color
- ☐ Completed item different size
- ☐ Place a symbol (">" or "*", etc.) in front of completed items
- ☐ Completed items indented two spaces
- ☐ Message changes for completed item - e.g., pump 1.....on to pump 1 on
- ☐ Combination of above
- ☐ Feedback not necessary
- ☐ Other (specify) _____

b. If changing color were used to indicate the completed items, which is more appropriate?

- ☐ Green for completed items, white for incompletd ones
- ☐ White for completed items, green for incompletd ones
- ☐ _____ for completed items _____ for incomplete ones
(fill in) (fill in)

Comments _____

10a. If the procedure is too long to be presented on one page, how should multiple pages be indicated?

☐ Symbol at bottom left of each page (" ")

☐ Symbol at bottom right of each page (" ")

☐ Page number at top right of each page ("2 of 4")

☐ Page number at bottom right of each page ("2 of 4")

☐ Word at bottom left of each page ("continued", "more")

☐ Word at bottom right of each page (e.g., "continue", "more")

☐ Indication is not necessary

☐ Other (please specify) _____

Comments _____

10b. If the procedure is too long to be presented on one page, should provisions be made to permit the crew to read and page through the checklist before taking any action?

☐ Yes it is absolutely essential

☐ It would be a benefit but it is not necessary

☐ No, it is not needed

Comments _____

11. Should voice messages be used to present action items? (e.g., "THROTTLE CLOSE" or "THROTTLE") Check as many as appropriate.

a. Voice messages should be used:

- ☐ As the sole source of information
- ☐ In combination with the visual display
- ☐ Upon crew command by a dedicated switch
- ☐ Automatically, after cancellation of the master caution and warning switch
- ☐ Automatically, after the completion of each action item
- ☐ Never; voice messages should not be used to present action items

b. If voice messages are used, they should be:

- ☐ Repeated automatically at specified time intervals
- ☐ Repeated upon crew request
- ☐ Other (please specify) _____

Comments _____

12. Which of the following presentation formats should be used to present voice messages?

- ☐ "TURN PUMP 2 OFF"
- ☐ "PUMP 2 OFF"
- ☐ "PERFORM STEP"
- ☐ The voice message should match the visual message whatever it is.
- ☐ Other _____

Comments _____

13.a. How should the procedures display be called up (i.e., initiate action item presentation, move to successive pages, and clear the display)? (Check as many as are appropriate.)
(See Figure B-2)

- ☐ Automatically, when an alert first appears on the alerting alphanumeric display
- ☐ Automatically, after cancellation of the master caution and warning switch
- ☐ Automatically, for warning alert and manually for other alerts
- ☐ Manually, by pressing a line select key on alerting display
- ☐ Manually, by pressing a line select key and then pressing the "PROCEDURES" OR "CHECKLIST" key on a dedicated keyboard
- ☐ Other _____

b. How should the crew interact with the procedures display? (This does not include performing the action items.)

- ☐ By voice command
- ☐ By touching the display surface
- ☐ By pressing dedicated keys adjacent to the action item
- ☐ By using a separate keyboard

Comments _____

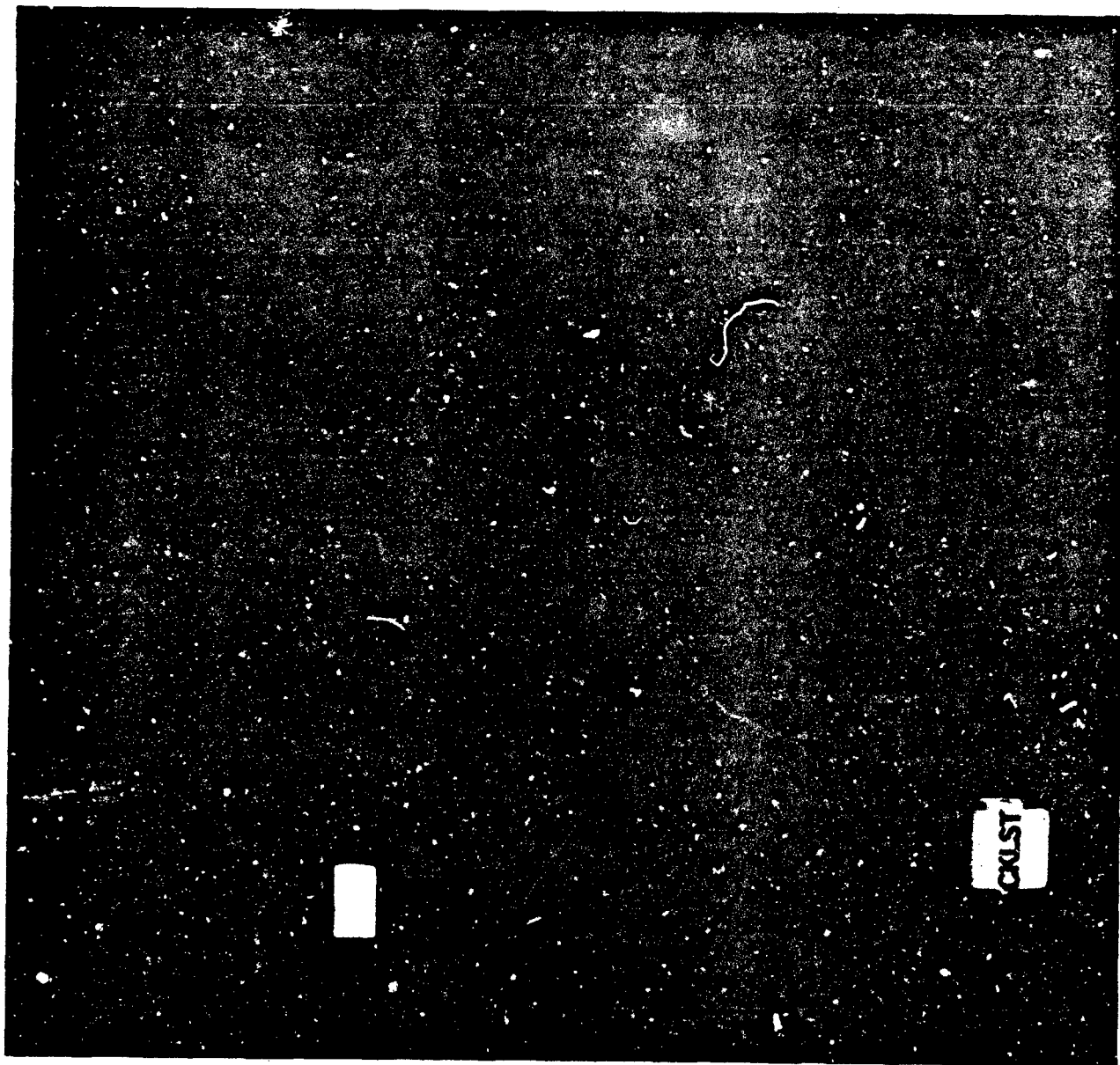


Figure B-2 The Alert Display

- 14.a. If the crew is in the middle of a checklist for a caution or advisory-level alert, and another alert occurs, how should the incompleted checklist be handled? (Assume the new alert is the same alert level)

- ☐ Remove and store the current checklist and display the new checklist
- ☐ Display the current checklist until it is complete and then display the new one
- ☐ Display both checklists with the current one at the top of the display and the new one on the bottom
- ☐ Display both checklists with the current one on the bottom of the display and the new one on the top
- ☐ Have the new checklist integrated with the current checklist. The integrated checklist items would be rank-ordered by criticality.
- ☐ Other (Specify) _____

Comments _____

- b. What would your response have been if the new alert was a warning-level alert? Mark the selected response with a "W".

15. Should the procedures display be cleared automatically after the last action has been performed, or should the crew be required to manually clear the display?

- ☐ Automatically
- ☐ Manually by crew

Comments _____

16. After an alert is signalled, and perhaps simultaneously with the display of procedures, there are a number of pieces of information that can be presented. Mark the following in the order you would like to see them (1 = the first information needed and 4 the last)

_____ Aircraft status information (including operational limitations) which permit the crew to assess the situation with respect to the establishment of proper flight path and airplane configuration.

_____ System status information permitting the crew to evaluate the system that caused the alert and its potential effect on the flight.

_____ Procedural status information providing the crew a graphic representation of the subsystem component which will be manipulated by the first action item on the procedures display.

_____ A combination of the above (please specify) _____

Comments _____

II. Status Displays

The purpose of the status display is to provide the crew with feedback concerning the present status of the flight and the aircraft and its systems. The information presented on this display encompasses a number of levels of information.

- o Aircraft Status - Provides an overall indication of aircraft status including the operability of all control surfaces, engines, flight controls, landing gears, etc. In addition, alphanumeric information describing the impact of degraded system capability will be provided (i.e., operational limits, diversions, environmental constraints, policy, etc.) Figure B-3 presents an example of an aircraft status display.
- o Failed System Status - provides a representation of the system that has produced the alert situation. The information presented about the system would include switch and valve position, operation parameters of the system (flows, temperature, pressures, etc.) and malfunctioning components. Figure B-4 is an example of the Failed System Status Display.
- o Procedural Status - as the procedural action items (checklist) are being performed, the crew may interact with various aircraft systems or system components. The procedural status display provides the crew a representation of the system or system component being addressed by the action item being worked. Figure B-5 presents an example of this display.
- o Information - the lowest information level of the status display present the supplementary information currently found in the handbook. Figure B-6 is an example of this display.

Please answer the following questions concerning the status display.

A. Aircraft Status Display

1. How important do you feel it is to provide the aircraft status for alerts?

_____ Necessary

_____ Beneficial

_____ Not needed

_____ May have negative effect

_____ Unacceptable

Comments _____

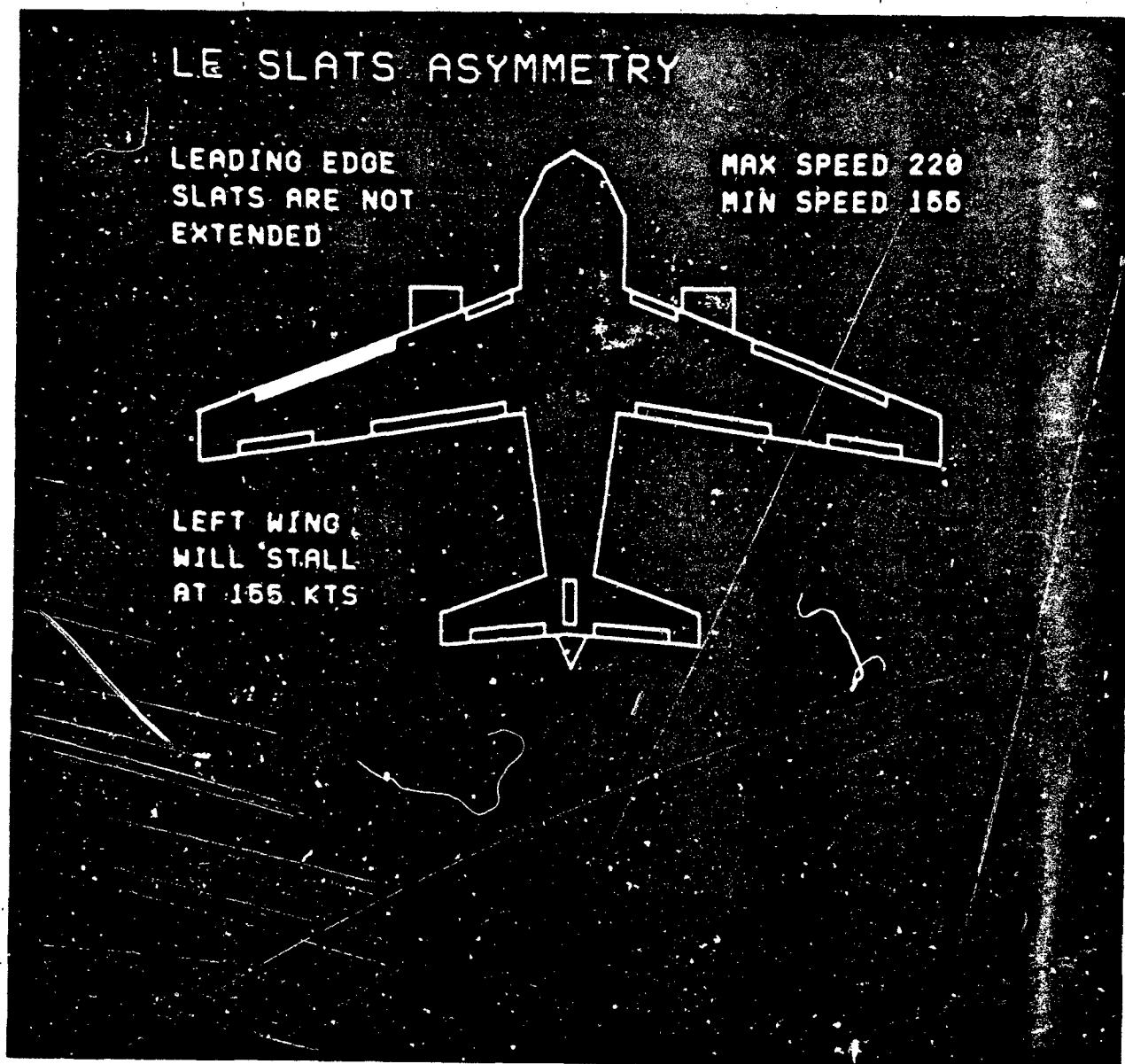


Figure B-3 Aircraft Status Display Format

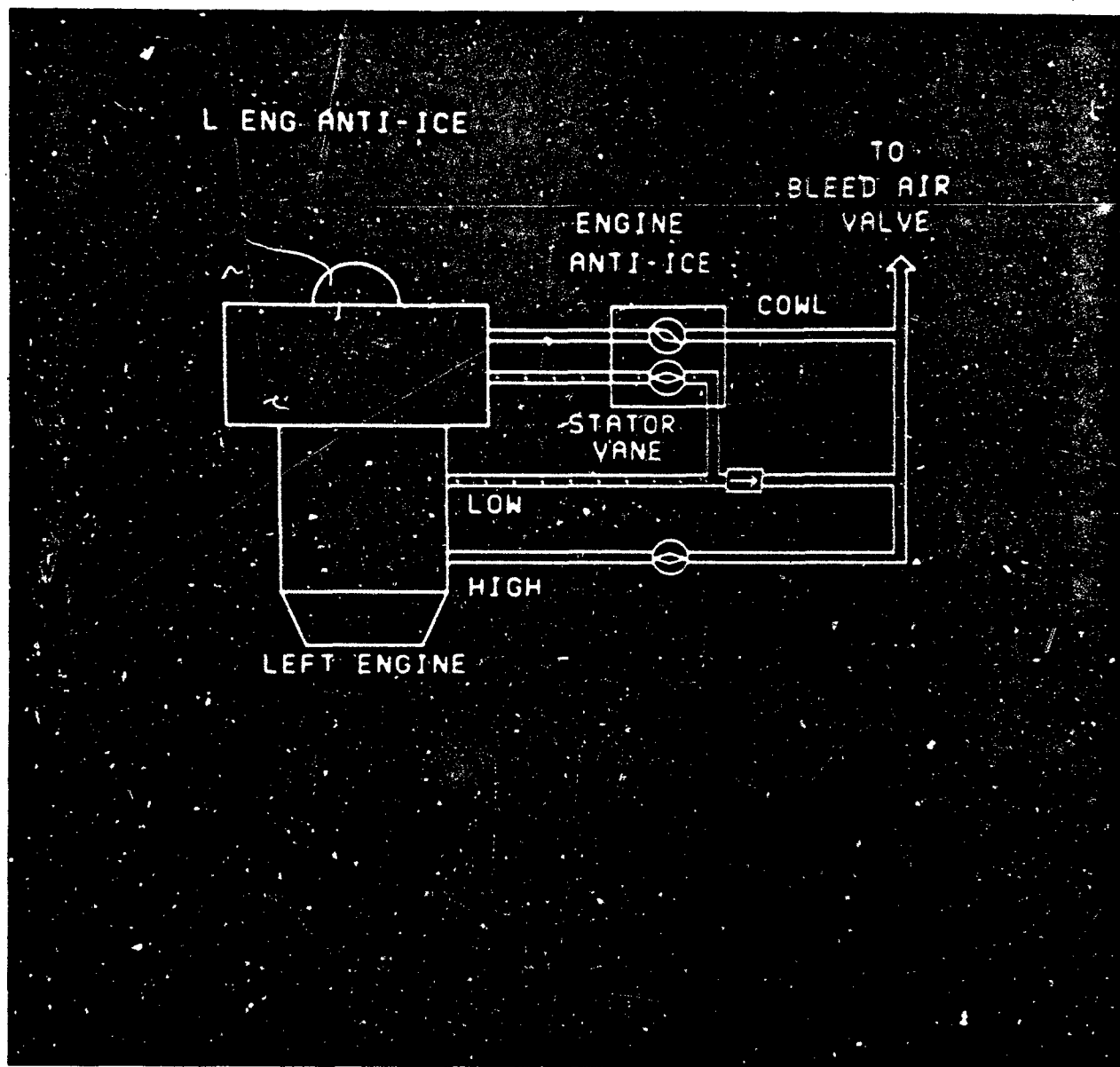
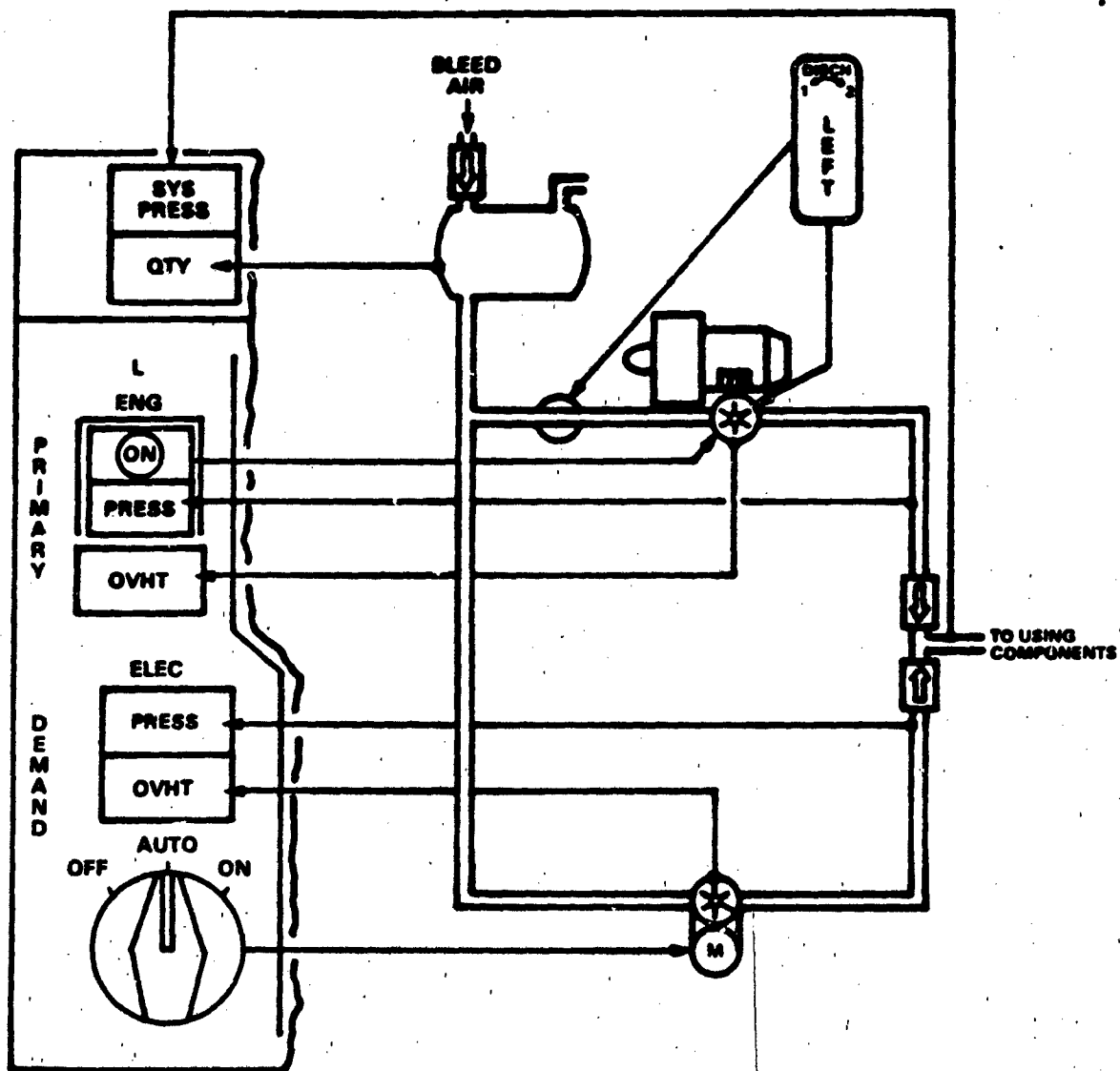


Figure B-4 Failed System Status Display Format



NOTE: RIGHT SYSTEM SIMILAR

Figure B-5 Procedures Status Display Format

L ENG ANTI-ICE

ICING CONDITIONS EXIST. TOTAL AIR
TEMPERATURE IS BELOW 10 DEG. C.

ICING CAN OCCUR WHEN
VISIBLE MOISTURE IN ANY FORM IS
PRESENT SUCH AS FOG WITH VISIBILITY
LESS THAN ONE MILE, RAIN, SNOW,
SLEET, ICE CRYSTALS, ETC.

ICE BUILDUP MAY RESULT IN SEVERE
ENGINE DAMAGE AND/OR FLAMEOUT

ERRATIC EPR INDICATIONS OR ABNORMAL
EPR RELATIVE TO NI MAY BE AN
INDICATION OF ENGINE ICING

Figure B-6 Operational Information Display Format

2. What information should be presented on the aircraft status display? (Check all that are appropriate.) (Refer to Figure B-3)

- ☐ System faults (e.g., failed hydraulic pump or failed generator, etc.)
- ☐ Operational status of the Comm/Nav. Equipment (i.e., radios, guidance equipment, etc.)
- ☐ Operational status of landing gear, brakes, steering tires, etc.
- ☐ Operational status of the engines
- ☐ Operational status of flight control surfaces (i.e., flaps, slats, rudder, etc.)
- ☐ Operational limits (i.e., speed limits, diversions, environmental constraint, policy, etc.)

Comments _____

3. Which mode(s) of presentation should be used to show aircraft status?

- ☐ Written list (e.g., operational limits, diversions, etc.)
- ☐ Pictorial outline of aircraft and pictorial representation of the systems as shown in Figure B-3.
- ☐ Combination of the above
- ☐ Other _____

Comments _____

4. How should information be coded or formatted on the aircraft status display? (Check all that are appropriate)

☐ System symbols or characters should be color coded according to alert urgency level generated by the failure condition

☐ System symbols or characters should be brightness coded according to alert urgency level generated by the failure condition

☐ System symbols or characters should be color coded according to operational status using colors other than those used for crew alerting (red and amber may not be used)

☐ System, symbols or characters should be brightness coded according to operational status

☐ Symbol, shape, or written messages should be used to indicate operational status

☐ Quantitative information, (i.e., operational limits) should be presented in analog form (e.g., speed limit bars, flap limit drawing, etc.)

☐ Quantitative information should be presented in digital form

☐ Other _____

Comments _____

5. How and when should the aircraft status display be activated? (Check all that apply)

☐ Automatically, at flight phase change
☐ Automatically, when the alert occurs
☐ Automatically, when the procedure display is activated
☐ Automatically, at the completion of the fault procedure
☐ Manually by pressing a switch
☐ Manually by voice command

Comments _____

6. System Status Displays (Failed-System and Procedures System Status)

1.a. How important is the failed system status display in assessing system/aircraft condition? (Refer to Figure B-4)

☐ Absolutely necessary
☐ Beneficial
☐ Not needed
☐ May have a negative effect
☐ Totally unacceptable

- b. How important is the procedural systems status display in performing the non-normal procedures for alerts? (Refer to Figure B-5)

☐ Absolutely necessary
☐ Beneficial
☐ Not needed
☐ May have a negative effect
☐ Totally unacceptable

Comments _____

7. What should be presented on a systems display? Mark all that are appropriate. (Use an "F" for those that are appropriate for failed-system status and a "P" for those appropriate for procedural status)

☐ Operational status of the system components, i.e., position of switches, state of pumps, etc.

☐ Quantitative parameters, i.e., temperatures, pressures, levels, flow rates, etc.

☐ Faulted components

☐ Trend information, i.e., near limiting condition and abnormal rates

☐ Other _____

Comments _____

8. Should the failed-system status display provide greater levels of detail upon demand?

☐ Yes

☐ No

Comments _____

9. What type of presentation should be used for system status?

☐ Written lists

☐ Schematic diagrams, as illustrated in Figures B-4 and B-5

☐ Pictorial representative

☐ Combination of the above. Specify _____

Comments _____

10. How should the system status information be coded or formatted?
(Check all that are appropriate.)

☐ Symbol or character color coded according to alert urgency level generated by the failure condition

☐ Symbol or character brightness code according to alert urgency level generated by the failure condition

☐ Symbol or character color coded according to operational status using colors other than those used for crew alerting (e.g., red and amber may not be used)

☐ Symbol or character brightness coded according to operational status

☐ Symbol, shape, or written message which change according to operational level

☐ Quantitative information displayed on an analog scale (e.g., speed limit bars, flap limit drawing, etc.)

☐ Quantitative information displayed digitally

☐ Other _____

Comments _____

11. How should the crew interact with the status display (e.g., system selection, paging, and erasing)?

- ☐ Dedicated switch(s) on the display-control panel
- ☐ Multifunction switch(s) on a multifunction control panel
- ☐ A touch panel overlay on the status display
- ☐ Voice command

Comments _____

III. System Controls

Six candidate concepts for FSM design have been developed. The FSM concepts differ in their level of automation: manual, system aided and automatic. There are two FSM display-control concepts under the manual category: 1) manual display callup after an alert and 2) automatic display callup after an alert. With the manual method, aircraft system reconfiguration is accomplished on the systems overhead panel. The systems aided concepts include automatic display callup and the aircraft systems are controlled by innovative concepts in conjunction with the FSM displays including voice interaction, touch panel overlays, and a multifunction keyboard. The last concept is automatic reconfiguration which only requires the crew to give a go-ahead signal. This concept may be used in conjunction with any of the above concepts, but for this study it was implemented only in the multifunction keyboard concept. These concepts are described in more detail in the following paragraphs.

Basic Concept

The operation of the Basic concept is as follows. After an alert occurs, the crew cancels the master caution and warning indicator and reads the alert display to identify the fault. By pushing the line select and CHECKLIST keys, the alert procedure is displayed on the procedures display. If the crew pushes the STATUS key, the aircraft status is presented on the status display. By selecting the STATUS key again, the FSM will display the system with the first procedural action item.

The crew reads the checklist and performs the necessary actions on the overhead panel. If there is more than one page of procedures, the completion of the items on the first page will bring up the next page. By pushing the CHECKLIST key in rapid succession the crew may step through the procedure pages. After the procedures are completed, the crew may step through the status pages by pushing the STATUS key. After completion of the checklist procedures, the displays will be cleared. The alert message is removed from the alert display after the alerting

situation no longer exists, otherwise it may be cleared by line selecting the alert and selecting STORE.

Basic Concept with Automatic Display

This concept is the same as the above concept except when the crew pushes the line select key, the procedures and status displays will be brought up automatically. As the crew completes all the actions on a page, the next page will appear automatically. After the procedures are completed the crew may step through the remaining status pages.

Touch Panel Interactive Concept

In this concept, the procedures display and status display (aircraft status page) are called up by the pilot selecting the line address key on the alert display. The pilot performs the actions directly on the status display by using a touch sensitive surface. After stepping past the aircraft status page, the status display will contain a schematic representation of the first action-item system with computer generated touch keys to reconfigure the system. Feedback information is presented on both the procedures and status displays. Each action item will have a corresponding schematic diagram on the status display. This display is also touch interactive for calling up more detailed information, if desired.

Voice Interactive Concept

This concept uses voice for both messages and control of the displays and aircraft systems. Voice control actuation is optional, and both the displays and systems may be manually controlled as described under the Basic or Touch Interactive concepts. Voice messages are used to direct the crew's attention to alerts and to the actions to be performed if the alert is a time-critical alert.

After pushing the line select key, the pilot may select voice interaction by depressing the voice key. After the displays are called

up, the crew would select the first action item by saying "next" and the first action item would be annunciated. If the crew wants the message repeated they would say "repeat". To execute an action item, the crew says, for example, "pump 1 off" and the action is completed. The crew continues this process until all the procedures are completed. Feedback is presented visually on the procedures and status displays and may be presented by voice messages. After the procedures are completed a voice message is given to that effect.

Multifunction Keyboard Concept

This concept uses a multifunction keyboard with programmable keys and a scratchpad. The scratchpad display presents the alert procedures. Aircraft status is provided on the status display. The multifunction keyboard presents the sequence of control actions. This concept has also been termed "Directed Selection" because the multifunction keys can be programmed to present the sequence of actions to be taken by the crew.

The operation shows that after selecting the alert, the action items appear on the scratchpad. The actions that are interactive with the aircraft systems are presented in sequence on the multifunction keyboard. To perform the action items, the pilot must depress the corresponding multifunction key. This procedure is continued until all items are completed. Feedback is provided on the scratchpad and on the multifunction legends.

Automatic Reconfiguration Concept

Any of the systems aided concepts could incorporate pilot-initiated automatic system reconfiguration. For demonstration purposes, the multifunction keyboard concept was used to evaluate the feasibility of this control method. This concept requires the same steps to call up the scratchpad display. However, the crew has only to select one key to initiate the corrective action. Action and status feedback are presented upon the scratchpad display. The crew has the option to stop the reconfiguration at any time.

The following questions concern the method the crew uses to interact with the Flight Status Monitor.

1. Rank order each concept of performing the action item according to each of the following criteria. Place a "1" next to the most preferred concept and "5" next to the least acceptable concept for each criteria.

| Concept | : Ease of Use | : Probability of Error | : Ease of Training | : Overall Operability | : Overall Desirability |
|---------------------------|---------------|------------------------|--------------------|-----------------------|------------------------|
| Dedicated System Panel | : | : | : | : | : |
| Multifunction Keyboard | : | : | : | : | : |
| Touch Panel | : | : | : | : | : |
| Voice Command | : | : | : | : | : |
| Automatic Reconfiguration | : | : | : | : | : |

Comments _____

2. For a touch panel interactive system, which do you prefer?

_____ Touch area on the procedures display next to the procedural action items without a status display

_____ Touch area on the procedures display next to the procedural action items with a status display

_____ Touch area over the component symbol on status display, i.e. you touch the component you wish to change with a procedures display

_____ Action items appearing on the status display which has the touch area over the components symbols without a procedures display

_____ Other _____

Comments _____

3. If subsystem/system panels can be displayed and operated via touch interactive displays, would dedicated aircraft subsystem control panels still be required? (Assume that sufficient redundancy is provided to ensure system reliability)

☐ Yes

☐ No

Comments _____

- 4a. Should voice control be used as input to the FSM?

☐ Yes it is a necessary component

☐ It would be a benefit but is not necessary

☐ It should not be used

☐ Other _____

Comments _____

- 4b. If voice control is used, which of the following configurations do you prefer?

☐ Voice control only

☐ Voice in combination with a dedicated systems panel

☐ Voice in combination with a multifunction keyboard

☐ Voice in combination with a touch panel

☐ Other _____

Comments _____

5. For which FSM function(s) should voice control be used? (Check all that apply)

☐ Calling up the procedures display
☐ Calling up the status display
☐ Cancelling the masters alerts
☐ Selecting alerts for display of procedures/status
☐ Storing, recalling alerts
☐ Performing procedural action items
☐ Other _____

Comments _____

6. How should voice control be actuated?

☐ Dedicated or multifunction switch on a display-control panel (e.g., Figure B-2)
☐ Knee switch
☐ Mike switch
☐ Voice command (using a code word)
☐ Always be active during operation
☐ Other _____

Comments _____

7. If multilegend keys are used on a multifunction keyboard for system control, what should be presented on the legends?

_____ Procedure step number

_____ Procedure action item

_____ Identification of system component requiring reconfiguration

_____ Other _____

Comments _____

8. If an automatic reconfiguration system is used, which of the following features should be incorporated? (Check all that apply)

_____ Capability should be crew selectable

_____ Crew should have capability to see previous configuration (After automatic reconfiguration completed)

_____ System status should be provided after reconfiguration

_____ Automatic sequence should stop short of critical action item, (e.g., engine shut down, gear up/down)

_____ Crew should have the capability to stop the automatic sequence

_____ Other _____

Comments _____

9. If you had the responsibility for developing an FSM, which controls and displays would you implement to provide crew guidance and status information?

Controls _____

Displays _____

